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Final Report on a Program to
Develop a System for the Inspection
of Soldered Electrical Joints
Under Contract DA-30-069-507-ORD-3252
Covering the Period
March 4, 1961 through June 30, 1962

EK/ARD ED-866

Prepared for
Frankford Arsenal
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Submitted by

Eastman Kodak Company
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FOREWORD

This document is the final report on a project to develop a method and apparatus for the rapid inspection of soldered joints in electrical assemblies. The information contained is divided into two major sections: (1) a summary of the entire program and (2) a detailed discussion of the efforts accomplished during the final report period. The work was performed by the Eastman Kodak Company under the direction of Frankford Arsenal and in accordance with Contract DA-30-069-507-ORD-3252.

The inspection system described herein is basically a refinement of the commonly used visual inspection for surface defects of solder joints. By making these defects luminous under ultraviolet light, the visual inspection becomes more reliable, less time consuming, and less dependent on operator skill and judgement.

The system is useful for the inspection of soldered joints in any electronic assembly, but it is particularly applicable to printed circuit construction. It is non-destructive, compatible with any manufacturing rate, and sensitive enough to detect quality trends before obviously defective material is produced. The apparatus required is inexpensive and can be assembled from ordinary commercial items.

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I. INTRODUCTION

The knowledge that tin-lead "solders" have the capability to wet and join other metals is ancient from an historical standpoint, and soldering with tin-lead alloys has always been the most commonly used method of making permanent joints in electrical circuits. As the electrical and electronic industries grew rapidly during the first half of the twentieth century, substantial effort was expended to improve hitherto crude soldering techniques in order to reduce manufacturing costs and improve product reliability.

With the advent of military missiles and space vehicles and equally complex civilian gear, circuit reliability became increasingly important. Electrical component reliability was improved until a condition was eventually reached wherein circuit reliability was often limited only by the soundness of soldered joints between components. Agencies of industry and government have continuously worked to develop a means of improving soldered joint quality. For the most part, the emphases have been on a better control of the soldering process as well as a more careful visual inspection of joints for surface defects.

In 1960, Frankford Arsenal recognized the need for determining the quality of a completed soldered electrical joint, not only more adequately, but also in a nondestructive manner and as a separate step in the manufacturing process. A scope of work was prepared and industry was invited to submit proposals for the development of such an inspection method which would be more effective and less cumbersome than the existing visual inspection technique and universally applicable to the wide variety of electronic assemblies used in military gear.

On March 4, 1961, Contract DA-30-069-507-ORD-3252 was awarded to the Eastman Kodak Company to accomplish this objective on a best effort basis and to build a typical inspection apparatus. The award was predicated on a Kodak proposal to improve the existing method of visually detecting voids and discontinuities in the surfaces of the joint. The proposed method depended upon the tendency of a low viscosity, low surface tension, oily liquid to penetrate and become trapped in surface voids. By adding a fluorescent substance to the liquid, entrapped material could be detected by observing its fluorescence, revealing the presence, nature and location of the surface defects.

During the first two quarters of effort on this project, the feasibility of the proposed system was established. Standard test specimens, standard methods of producing soldered joints at various quality levels, and physical tests for use as primary standards to measure quality level were constituted and employed to develop and evaluate the process.

During the third report period, effort was expended to evaluate the system, but the major emphasis was placed on developing production orientated techniques for performing the essential steps in the inspection process. Preliminary designs of a production inspection apparatus were also started.

In the fourth quarter, laboratory evaluation of the system effectiveness was completed and a typical production inspection apparatus was designed and built. Section III of this report, contains a detailed description of the work accomplished during this final report period which extended from December 4, 1961 to May 15, 1962.

In Section II are summarized the results of the entire project which covered the period from March 4, 1961 to May 15, 1962. Included are a presentation of (1) the theory, (2) the general nature and capability of the system, (3) a description of the procedure for inspecting soldered joints, (4) a description of a typical apparatus needed to perform the inspection, (5) an analysis of the system advantages and disadvantages, and (6) a review of the pertinent laboratory data which support the reliability of the system.

II. FINAL SUMMARY REPORT

A. Theory, General Description and Capability of the Inspection System

It has long been a recognized fact in industry that an imperfectly soldered electrical joint usually contains imperfections such as voids or discontinuities on its surface. These may be caused by contamination of the unsoldered joint by "dirt" (such as oil) or by a chemically deposited film such as an oxide. Other common causes of poor solder flow and consequent surface defects are improper solder temperatures, improper amounts of flux, poor metallurgical properties of the solder, poor mechanical arrangement of the joint before soldering, etc. The presence of such surface flaws in poorly soldered joints is the basis for the visual inspection method in such widespread use today. This method is effective despite its cumbersome nature, its dependence on skilled operators, and its inability to detect flaws which are beyond the resolving power of the human eye, even when aided by optical magnifiers of the type that are practicable in a production line.

When the Eastman Kodak Company was considering various new approaches to solder joint inspection (in response to the Frankford Arsenal invitation for proposals), techniques which were not based on the known relationship between joint quality and voids on the joint surface were eventually discarded. They failed to meet the fundamental requirements for a process that was universally applicable and reliable. It therefore seemed most logical to consider ways of removing the natural limitations of the visual inspection.

method that was already in use and already proven to be fundamentally reliable. It further seemed logical to use existing commercially available systems for detecting surface flaws by the entrapment of low surface tension liquids. During the developmental program it was confirmed that such commercial systems could be employed.

To determine solder joint surface quality, the first essential step in the process selected is to cover the solder area with an oily liquid "penetrant" which has a low surface tension and which is easily drawn into voids and fissures by capillary action. This material has suspended in it a fluorescent substance which can later be used to detect its presence. After removing excess penetrant from the joint surface, a talc-like dust is applied to withdraw entrapped liquid from any surface defects. By examining the joint at this stage under ultraviolet light for spots of fluorescence, the presence, location and general nature of these defects can be determined. Even tiny imperfections are made visible because, when the penetrant is drawn into the powder, it tends to spread over a relatively large area. The exact procedures suggested and the typical apparatus developed for performing these steps will be discussed on pages 17-25.

The entire system has been found to be rapid and requires little operator training and judgement. It is applicable to the inspection of most electronic assemblies, but particularly to printed circuit construction. It has no harmful effect on circuit components and does not present any unusual health hazards to the operator. The equipment required in inexpensive, essentially commercially available, and compatible with any production line installation, regardless of output rate.

The direct relationship between surface defects and joint quality has been established by a large amount of laboratory data which are summarized in a later part of this report. These data compare joint quality as determined by the entrapped penetrant method against joint quality as determined by destructive physical testing.

These laboratory data have also established that if the penetrant system is used to monitor quality a soldering process under good control will produce detectable surface imperfections in 5 to 10% of the joints in an average assembly. In commercial practice, such an average percentage of "defective" joints per assembly could be used to maintain process quality control. For the more stringent requirements of military gear, the percentage of "defective" joints could be used to maintain control of the process and at the same time the individual "defective" joints could be repaired to insure extremely high reliability. That is to say that nothing in the inspection process inhibits repair and reinspection as many times as necessary to eliminate all traces of solder surface discontinuities.

When used to inspect assemblies employing printed circuit boards, the system has the additional capability of detecting other than soldering defects. Cracks in the board insulation, poorly adhered conductors, and edge or surface imperfections in the conductors entrap penetrant and are easily detected under ultraviolet light.

B. THE INSPECTION TECHNIQUE

The actual inspection procedure requires four basic operations as outlined and described below.

Spray on Penetrant

30 Seconds minimum delay

Spray on Trichlorethylene

Air dry

Dust on Powder

3 Minutes minimum delay

Inspection under Ultraviolet Light

Clean with air blast if desired

Flux residue must first be removed from the soldered joint surfaces in order to open voids and fissures so the penetrant can enter. The flux residue may also be fluorescent and thereby give a false indication of quality. Various effective washing techniques and equipment to remove excess flux after soldering are already normally used in industry. This is especially true on such products as military gear, where high reliability is important. The washing operation was therefore not considered to be an actual step in the subject inspection process.

1. Apply Penetrant

The penetrant is the commercially available Magnaflux compound, type ZL-22, which consists of a petroleum oil base containing approximately one to two per cent by weight of a fluorescent material. The oil base has a surface tension of 31.5 dynes per centimeter at 26°C and a ph of 7.0. The fluorescent substance has its peak absorption at 3650°A and peak emission at a wavelength of 535 millimicrons (yellow).

The liquid is applied to the soldered area without thinning or other preparation, using an ordinary paint spray gun. The only "critical" requirements are that a generous wet coat be applied to each joint surface and that the penetrant be allowed to "soak" into possible surface discontinuities for at least thirty seconds before performing the next operation.

2. Remove Excess Penetrant

Excess penetrant must be washed from all surfaces of the work with trichlorethylene, except that this washing cannot be so thorough that the penetrant is removed from any surface discontinuities that may be present. The trichlorethylene is applied as a spray under the following conditions:

Advisory:

Apparatus	-	Commercial paint spray gun
Nozzle Size	-	1/16-inch diameter
Air Pressure	-	5-psi gage

Mandatory:

Nature of spray	-	Fine mist
Spray Pattern	-	3 to 4-inch diameter circle at 8 to 10 inches from nozzle
Spray Rate	-	2.0 to 2.6 grams of trichlorethylene per second
Technique	-	Work held stationary in spray pattern, 7 to 10 inches from nozzle, for a time of 2 to 4 seconds

For large assemblies that cannot be contained in a three to four-inch diameter circle, the work can be covered in several passes to obtain the equivalent of the specified application time, or a larger spray pattern can be used provided that the spray rate is adjusted to the equivalent of that specified. Spray rate and time must be held within the tolerance bands given, since too little washing may not remove penetrant from surfaces that have acceptable quality, and too much washing may remove penetrant from significant surface defects.

After spraying, the work is allowed to air dry. Drying is not critical except that, if large areas of the work are wet when the operation which follows is performed, developer powder may become caked and degrade the appearance of the product. The trichlorethylene evaporates rapidly so that drying will occur within a few seconds on assemblies of average size.

3. Apply Developer

A fine talc-like "developer" powder must be liberally dusted over each joint surface to withdraw by capillary action any penetrant that may have been entrapped in surface discontinuities. The powder is commercially available as Magnaflux compound, type ZP-4. It has particle sizes to a maximum of approximately forty microns.

In order to quickly apply a uniform coat of powder, a technique and apparatus have been developed whereby the work is held for a minimum of five seconds on the surface of an agitated bed of the material. The apparatus is described in detail on page 23.

After the powder is applied, a minimum of three minutes must be allowed before the next operation is performed, so that entrapped penetrant can properly spread into the powder coat.

4. Visually Inspect

Finally, the work is visually examined under ultraviolet light for the presence of fluorescent spots. The recommended light source is a standard item and is described on page 24.

For developmental purposes, any sign of fluorescence was considered to be cause for rejecting a joint. However, if the inspection process were being used to monitor actual production, the information could be used in any one of a number of ways.

a. The ratio of "rejected" joints to the number of joints inspected could be used to indicate process quality, and all joints could be accepted provided that a predetermined maximum ratio was not exceeded.

b. "Rejected" joints could be marked and set aside for later evaluation under ultraviolet and visible light by technically qualified personnel to determine whether (1) repairs are or are not necessary, (2) the manufacturing process needs correction, or (3) the product design should be corrected.

c. "Rejected" joints could be marked and set aside for repair and reinspection.

The very thin developer powder coating that remains on the work after visual inspection will probably not be detrimental to the product

Figure 1 PROPOSED FACILITY FOR THE INSPECTION OF SOLDERED JOINTS

appearance of function in the majority of cases. However, it can be removed by a blast of air if necessary.

C. TYPICAL INSPECTION APPARATUS

A photograph of a typical apparatus for carrying out the penetrant inspection process on a production basis is shown in Figure 1. This equipment is made up of three modules with Formica-covered working surfaces. At the first station, facilities are provided to apply penetrant and remove the excess. Application of developer powder and inspection under ultraviolet light are performed at the second and third stations, respectively.

The first station has a drained sump to catch waste penetrant and trichlorethylene, and a baffled, ventilated hood to remove vaporized material. Two pressurized containers equipped with liquid level gages contain supplies of the penetrant and trichlorethylene, and are each connected with flexible hoses to the liquid input port of a spray gun. Storage capacity is provided for two gallons of penetrant and five gallons of trichlorethylene. A calibrated fluid flow gage is placed in the trichlorethylene supply line to assist in setting up the apparatus for the proper application rate.

Oil-free compressed air is supplied to the overall facility, including the spray guns and pressurized containers, by a 1/3 horsepower, diaphragm-type compressor. The supply line to each tank and gun pair contains a pressure regulator and pressure gage. The penetrant gun requires approximately one pound of gage pressure and the trichlorethylene gun requires approximately eight pounds.

The second station contains the apparatus shown schematically in Figure 2 for applying developer powder to the work. Oil-free compressed air from the previously mentioned source is supplied through a pressure regulator and gage to the closed end of a cylindrical steel tank. This air diffuses through a cast porous (Norton P-280) stone during its escape to the open end of the tank. The developer powder is placed above the stone and a slowly rotating, motor-driven agitator blade is located in the powder bed, close to the top surface of the stone. With approximately 2.5 pounds of air pressure supplied to the device, the powder bed "flows" so that work placed just below its surface is quickly and evenly coated with powder. A ventilated exhaust hood surrounds the bed to carry away particles of the powder that may escape into the air.

The third station is basically an enclosure to permit examination of the work under ultraviolet light in a normally illuminated area. Light baffled openings are provided in the enclosure walls for inserting, holding, and viewing the work. The viewing window is hooded to reduce visible light leakage and for operator comfort. The enclosure contains two Sylvania F 15T-8-BLB blacklight blue tubes having a peak radiation of 3660°A. The lamps are supported in a reflector to give a 108° beam with an intensity of 459 milliwatts per square centimeter at a distance of 18 inches.

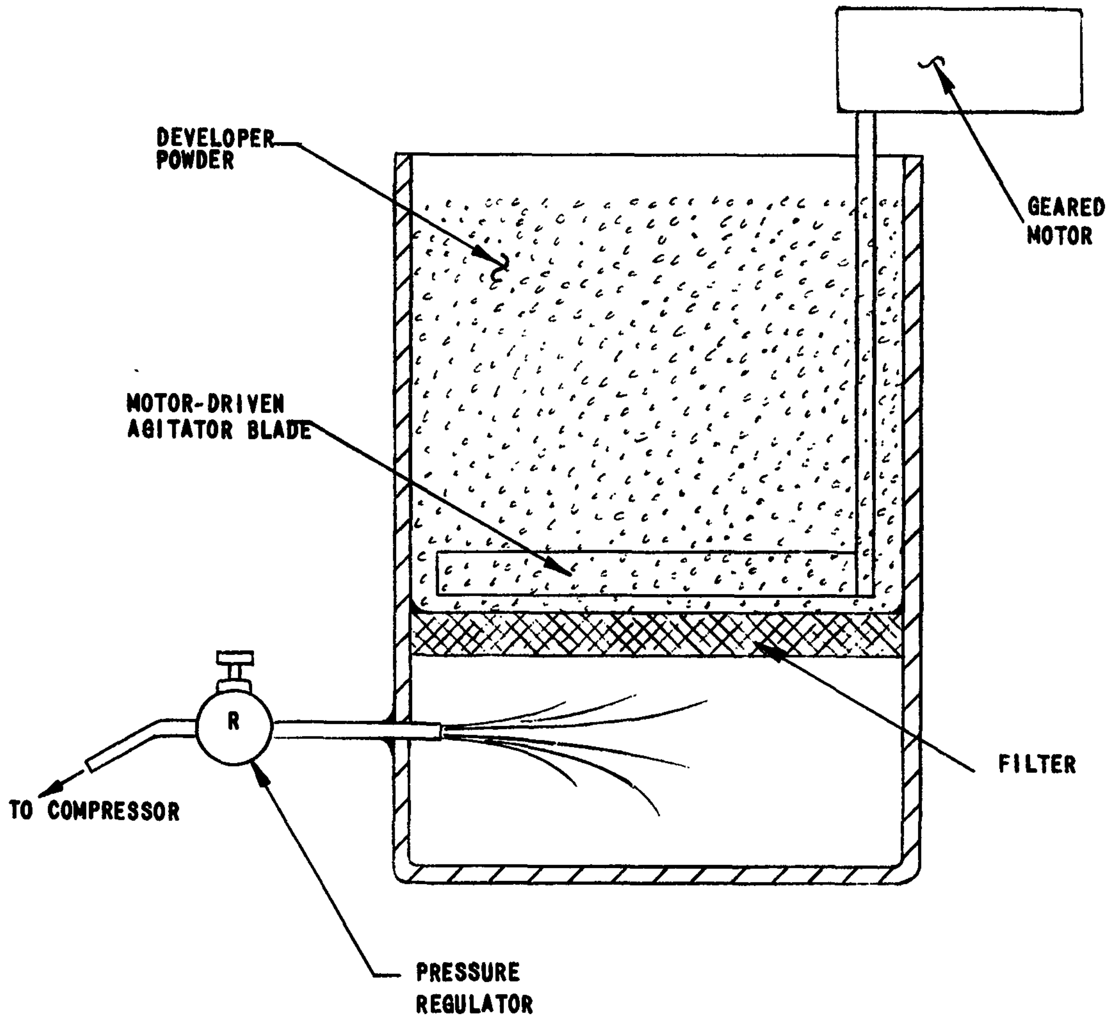


Figure 2. SCHEMATIC DIAGRAM OF FLUIDIC BED

D. ANALYSIS OF THE SYSTEM'S ADVANTAGES AND DISADVANTAGES

It has been emphasized that the penetrant inspection system is based on improving the effectiveness of presently used visual methods; therefore, its application does not require radical changes to existing product designs, nor does it impose extreme restrictions on new product designs. However, by observing certain design precautions, which are discussed on pages 26 and 27, the efficacy of the inspection operation is enhanced.

The materials and apparatus as required by the system are essentially inexpensive, off-the-shelf items. Compared to presently used visual methods, the penetrant process is faster, more reliable and requires less operator skill and judgement. It is much more sensitive to small changes in quality with the result that it can be used to detect quality trends before obviously defective material is produced. It does not expose the operator to any health hazards. The process is compatible with any production rate and does not harm the product except that the trichlorethylene used as a solvent may attack certain inks.

The effectiveness of any visual inspection method and particularly of the penetrant system is enhanced if soldered joints are designed to be readily visible, and present no sharp changes in surface contour. For instance, joints formed by wrapping a wire or several wires around a terminal post are likely to have deep crevices unless unusual care is taken during soldering. The quality of the solder bond in these crevices must be estimated and if the penetrant inspection system is used, the crevices will entrap penetrant and appear as surface defects. As another instance, joints in printed circuit wiring, wherein wire leads are clipped nearly flush with the board terminal before soldering, are likely to have the wire end completely buried in a ball of solder. Under these conditions, the quality of the bond between the wire end and the solder cannot be observed.

It is apparent that the penetrant system is most effective for the inspection of soldered joints in assemblies which employ printed circuit boards and wherein terminal wires are allowed to protrude through the soldered surface of the finished joint. However, it is equally apparent that this latter requirement should be observed if commonly used visual inspection techniques are to be reliable, unless joint quality is to be painstakingly estimated from circumstantial evidence by highly trained technical personnel.

E. DATA SUPPORTING THE SYSTEM RELIABILITY

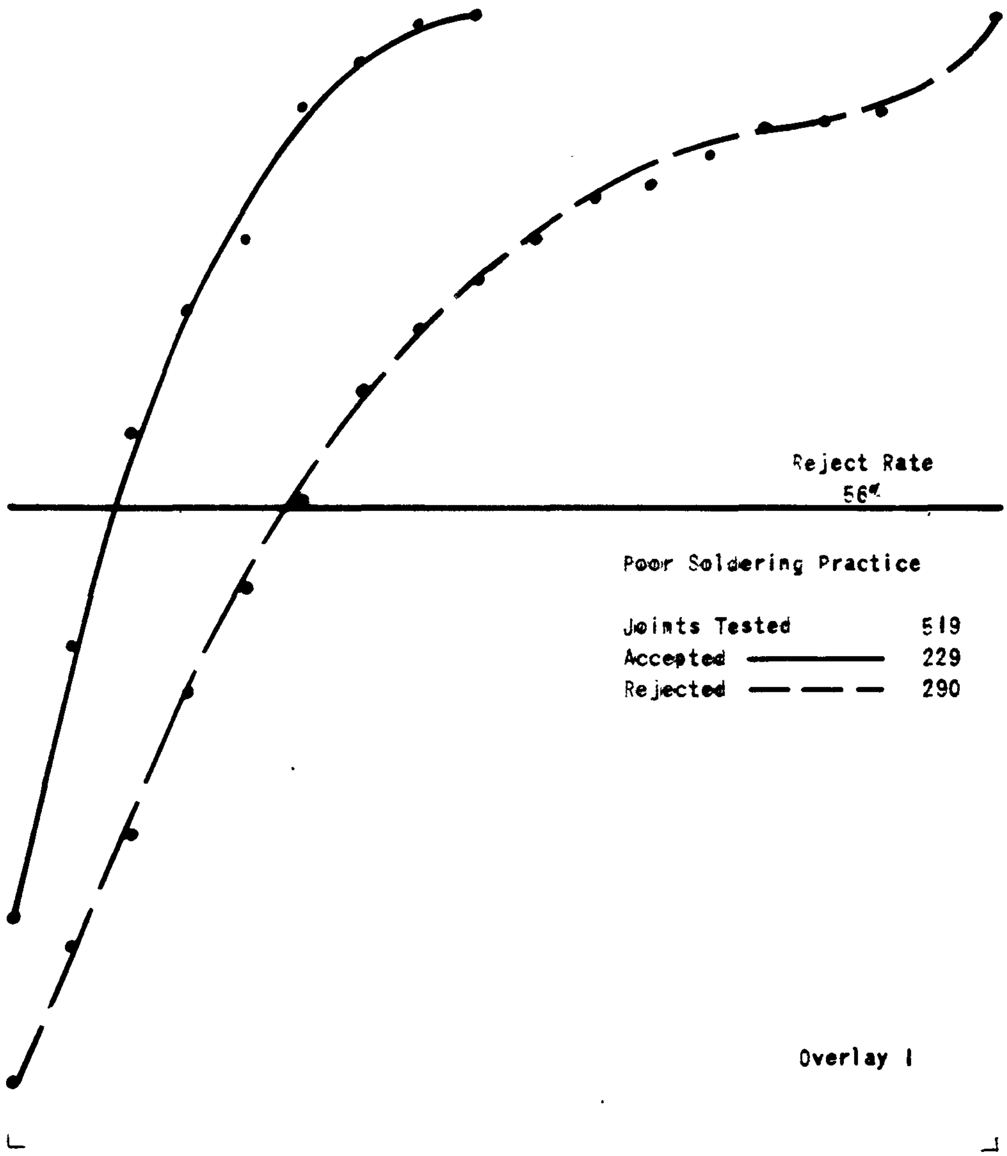
During the initial phase of the project, the set of standards described in Appendix A was established to assure an orderly development and evaluation of inspection techniques. Standard test assemblies, standard methods for making soldered joints at various quality levels, physical tests to serve as primary standards, and environmental tests for evaluating joint ruggedness are defined. During the life of the program, these standards were used to accumulate a large amount of test data which are reported in detail in each of three published progress reports and in Section III of this report.

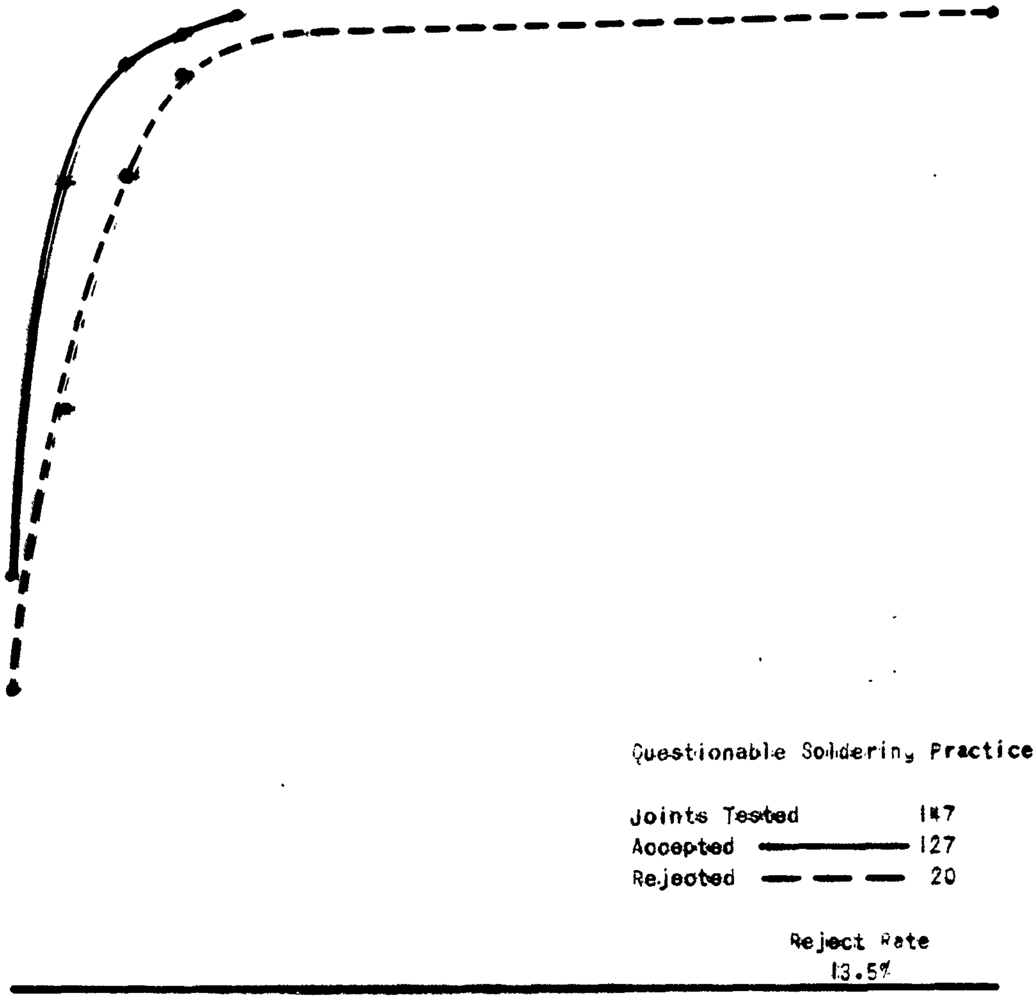
Pertinent parts of these data are summarized in the immediately following text and graphs to indicate the reliability and performance that can be expected when the penetrant system is used.

The standards contained in Appendix A specify several alternate circuit boards, several methods for varying joint quality, and several kinds of physical tests. The data presented in the following summary were taken using the standard circuit board containing phenolic insulation and plain copper, drilled hole terminals. For simplification of the summary presentation, joint quality is indicated by classifying the soldering practice as good, questionable or poor. The physical test used as a primary standard in accumulating the summarized data was always the tensile pull test described in Appendix A.

Figure 3 with its two overlays presents accumulated data taken for joints that were simply soldered, inspected for quality by the penetrant process, and finally tested for physical strength. The data are arranged to compare the results of the inspection with penetrant against physical strength. A total of 1068 joints are represented, including 402 that were produced under conditions typical of good soldered practice, 519 produced under conditions that were typical of poor soldering practice, and 147 produced under conditions of questionable practice.

It can be seen that good soldering practice resulted in a reject rate of 5.5% when the work was inspected by the penetrant process. No joint had a physical strength of less than 12 pounds, but the curves indicate that


Reject Rate
56%
Poor Soldering Practice
Joints Tested 519
Accepted 229
Rejected 290
Overlay I


Questionable Soldering Practice
Joints Tested 147
Accepted 127
Rejected 20
Reject Rate
13.5%

Overlay 2

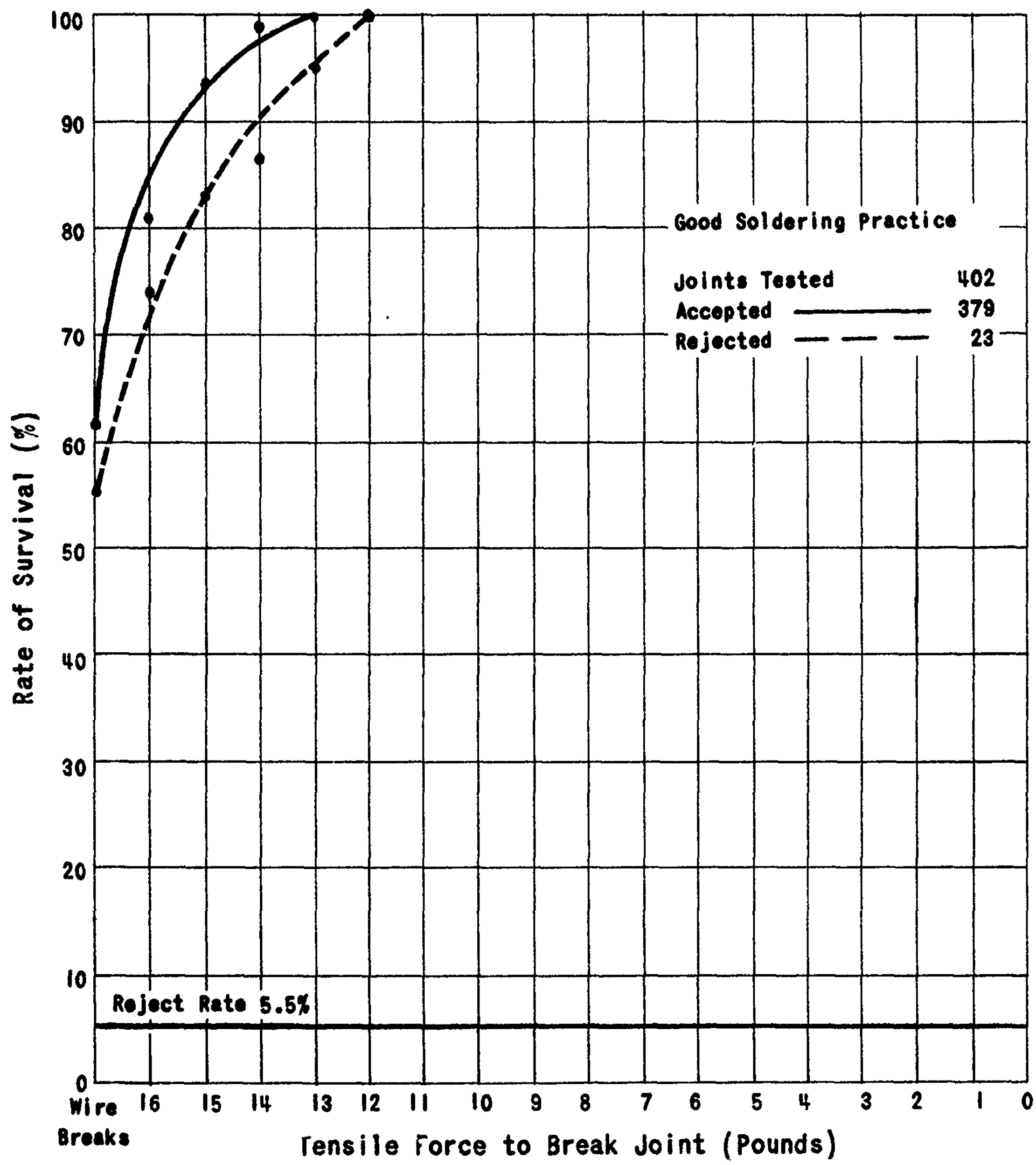


Figure 3. JOINT QUALITY AS DETERMINED BY THE PENETRANT PROCESS VERSUS PHYSICAL STRENGTH

rejected joints generally had slightly lower physical strength than accepted joints.

Poor soldering practice resulted in a reject rate of 56% and a minimum physical strength of 9 pounds for accepted joints. The curves show a marked difference in average strength between accepted and rejected joints. Approximately 25% of the rejected joints would not withstand 9 pounds of pull.

When questionable soldering practice was used, the reject rate was 13.5% and the minimum physical strength of accepted joints was 13 pounds. Rejected joints generally had less strength than accepted joints and a small percentage of the rejected joints had very poor strength.

It can be concluded from the data presented in Figure 3 that:

1. The penetrant process can be relied upon to sort out obviously defective soldered joints.

2. Even "good" soldering practice will result in a small percentage of joints being rejected by the penetrant system of inspection. Under these conditions, the average physical strength of rejected joints is slightly lower than that for accepted joints.

3. Relatively small departures from good soldering practice result in relatively large increases in the percentage of joints rejected by the penetrant system. Thus, the system can be used to predict quality trends and exercise effective quality control over the manufacturing process.

In Figure 4 is presented a graphic summary of the results of testing conducted to determine the effect of vibration on soldered joints

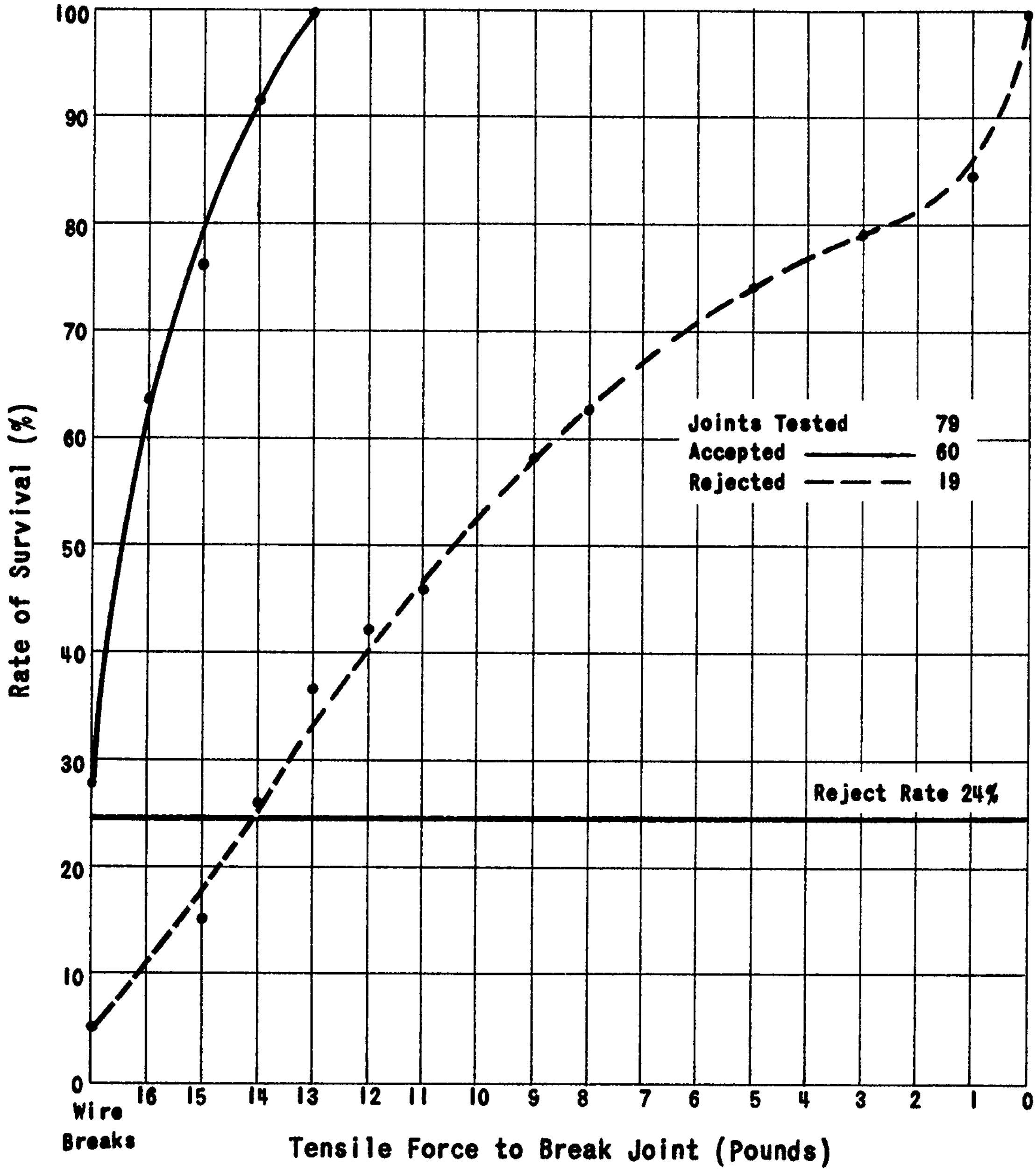
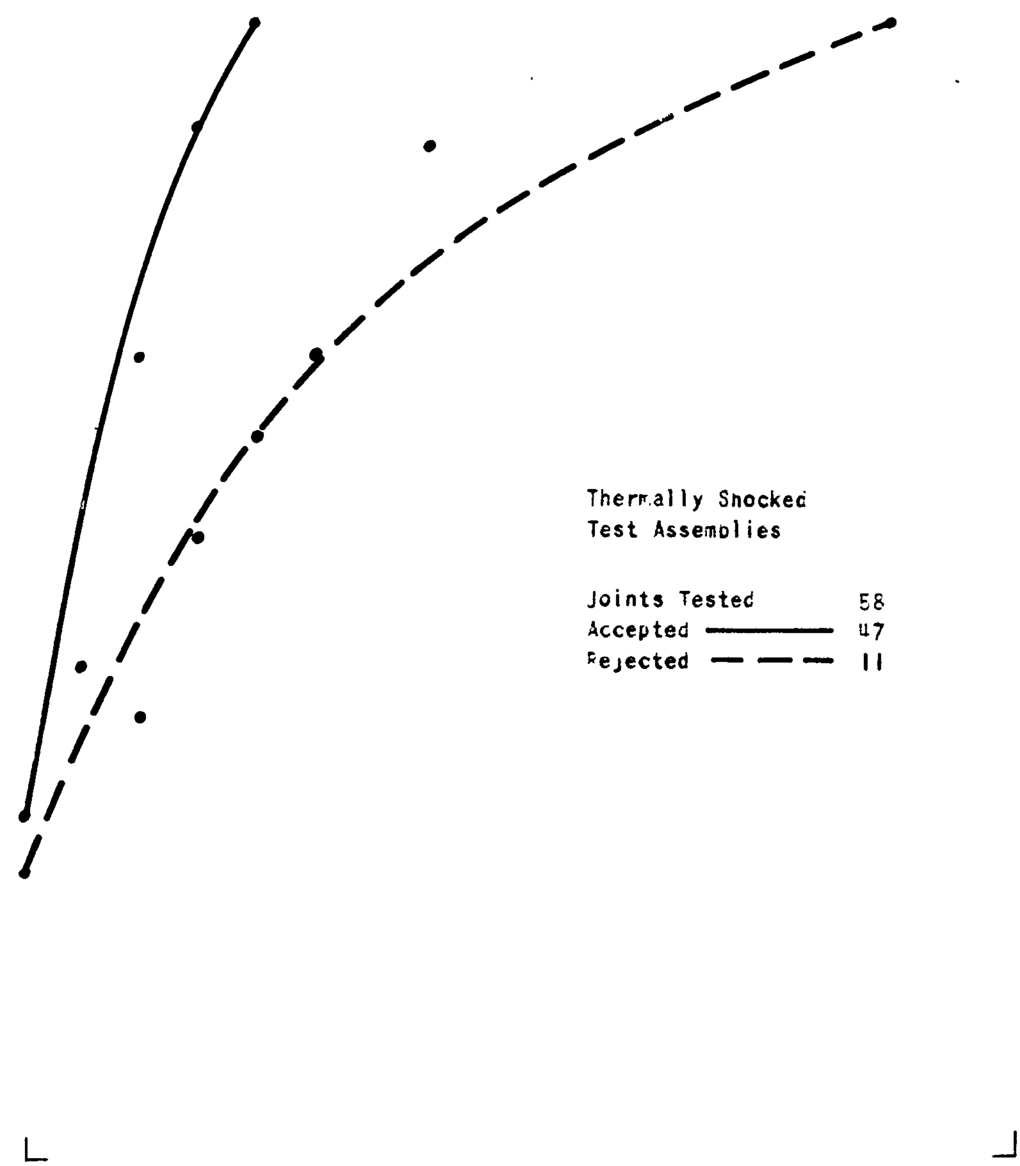


Figure 4. JOINT QUALITY AS DETERMINED BY THE PENETRANT PROCESS VERSUS PHYSICAL STRENGTH AFTER VIBRATION

accepted by the penetrant inspection system. Data are presented for a total of 79 joints of random quality. These were inspected by the penetrant process and found to contain 19 rejects. The entire group was then subjected to the vibration test described in Appendix A. Some joints were vibrated at an ambient temperature of -65°F, some at 75°F and some at 165°F. Some were subjected to one of the vibration cycles described in the appendix and others were subjected to two or three cycles. After vibration, all joints were tested for physical strength.

It can be concluded from the data shown in Figure 4, that soldered electrical joints accepted by the penetrant inspection system do not deteriorate as a result of exposure to vibration. It is assumed, of course, that the product design is in itself adequate to withstand the vibrational forces.

Data taken to determine the effect of thermal shock on soldered joints accepted by the penetrant process are presented graphically in Figure 5 and its overlay. A total of 114 joints of random quality were tested. Of these, 56 which were used for controls were simply inspected by the penetrant process and then tested for physical strength. The remaining 58 were similarly inspected, exposed to the thermal shock cycle described in Appendix A, and then tested for physical strength. The curves shown demonstrate that soldered joints accepted by the penetrant process do not deteriorate when subjected to severe thermal shock.


Thermally Shocked
Test Assemblies
Joints Tested 58
Accepted 47
Rejected 11

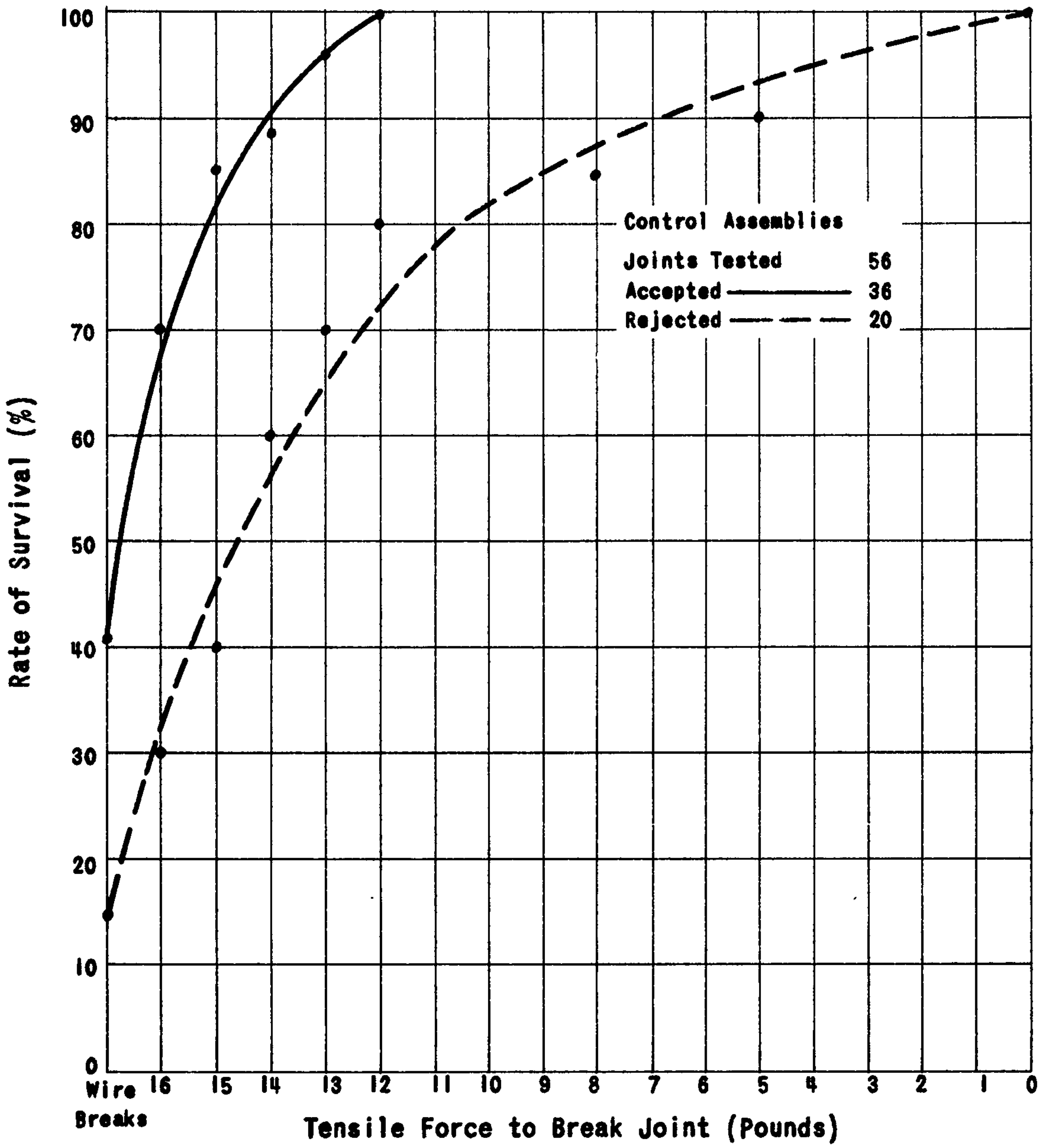


Figure 5. JOINT QUALITY AS DETERMINED BY THE PENETRANT PROCESS VERSUS PHYSICAL STRENGTH AFTER THERMAL SHOCK

III. FOURTH PERIOD PROGRESS REPORT

The penetrant system described in Section II was developed and partially evaluated by the Eastman Kodak Company during the first three periods of the subject program. Also, some of the apparatus required to perform the inspection operations had been constructed. During the fourth and final period, evaluation of the system effectiveness was continued, principally to determine its usefulness when employed to inspect a greater variety of electronic assemblies than those hitherto tested in the program. A study, started earlier in the project, to determine the effects of vibration on soldered joints accepted by the penetrant system was completed. A final check was made to determine the effects of the system on product shelf life and on operator safety. The typical production type inspection facility required by the scope of work for the program was designed and constructed.

With the approval of the Frankford Arsenal, this final reporting period was extended from three months to four months duration.

A. CONTINUED EVALUATION OF SYSTEM EFFECTIVENESS

During the first weeks of the project, the standard test circuit boards described in Appendix A were established in order to accomplish an orderly developmental program. Almost all of the test data accumulated and reported during the first three quarters of effort were taken with the standard board which contained phenolic insulation and plain copper, drilled-hole terminals. In this, the final period, testing by the penetrant process and checking for physical strength was extended to include other types of standard boards (described in Appendix A). A limited number of random commercial assemblies procured from local industry were also tested.

1. Inspection of Standard Test Assemblies

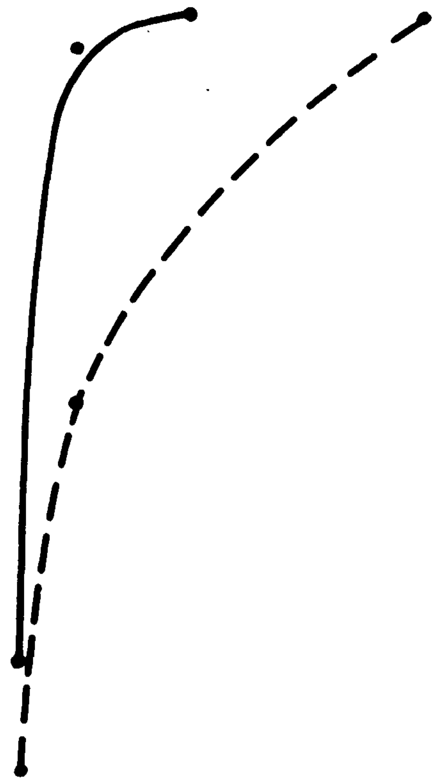
The standard test circuit boards all have a common configuration and the same circuitry, formed by etching. Variations include (1) the type of insulating material, which can be either XXXP phenolic or G-10 glass fiber and epoxy resin, (2) the terminal style, which can be a plain drilled hole, an eyeletted hole, or a wrap around terminal post, and (3) the terminal finish, which can be copper, solder or gold.

Engineering judgement would indicate that there should be no difference in the effectiveness of the penetrant inspection process if the insulating material and terminal finish were varied and if the terminal was changed from a drilled hole to an eyeletted hole. However, limited testing was performed for confirmation. It can be seen from the detailed results in Appendix B,which are summarized in Figure 6 (Page 37)and Figure 7 (Page 39), that the results are essentially the same as those obtained in earlier tests reported during the previous quarters of the program.

It can be concluded that when an electronic assembly is constructed on a circuit board wherein component wires are inserted through terminal holes and allowed to protrude through the final soldered joint surface, the penetrant inspection system is effective regardless of the board insulation material, the board terminal finish, and the exact geometry of the terminal hole. Under these conditions, the system will positively reject all joints that are physically weak. The percentage of rejected joints will be directly proportional to the extent to which the soldering process departs from good practice. A small percentage of physically strong joints will be rejected even though good soldering practice was employed and the average strength of these rejects will be slightly less than that for accepted material.

A small number of standard test assemblies with wrap-around terminals were also tested to determine the effectiveness of the penetrant inspection system on this type of construction. The data obtained are also presented in Appendix B. It was found that the wrap-around joint was more difficult to inspect than the plane surface joints previously evaluated. It took longer to coat, wash and visually scan all of the surfaces of the cylindrical terminal. The solder surface tended to be naturally rough so that a significant amount of judgement was required to classify the joint quality, and the mechanical joint between the terminal and the circuit board tended to entrap penetrant and therefore fluoresce.

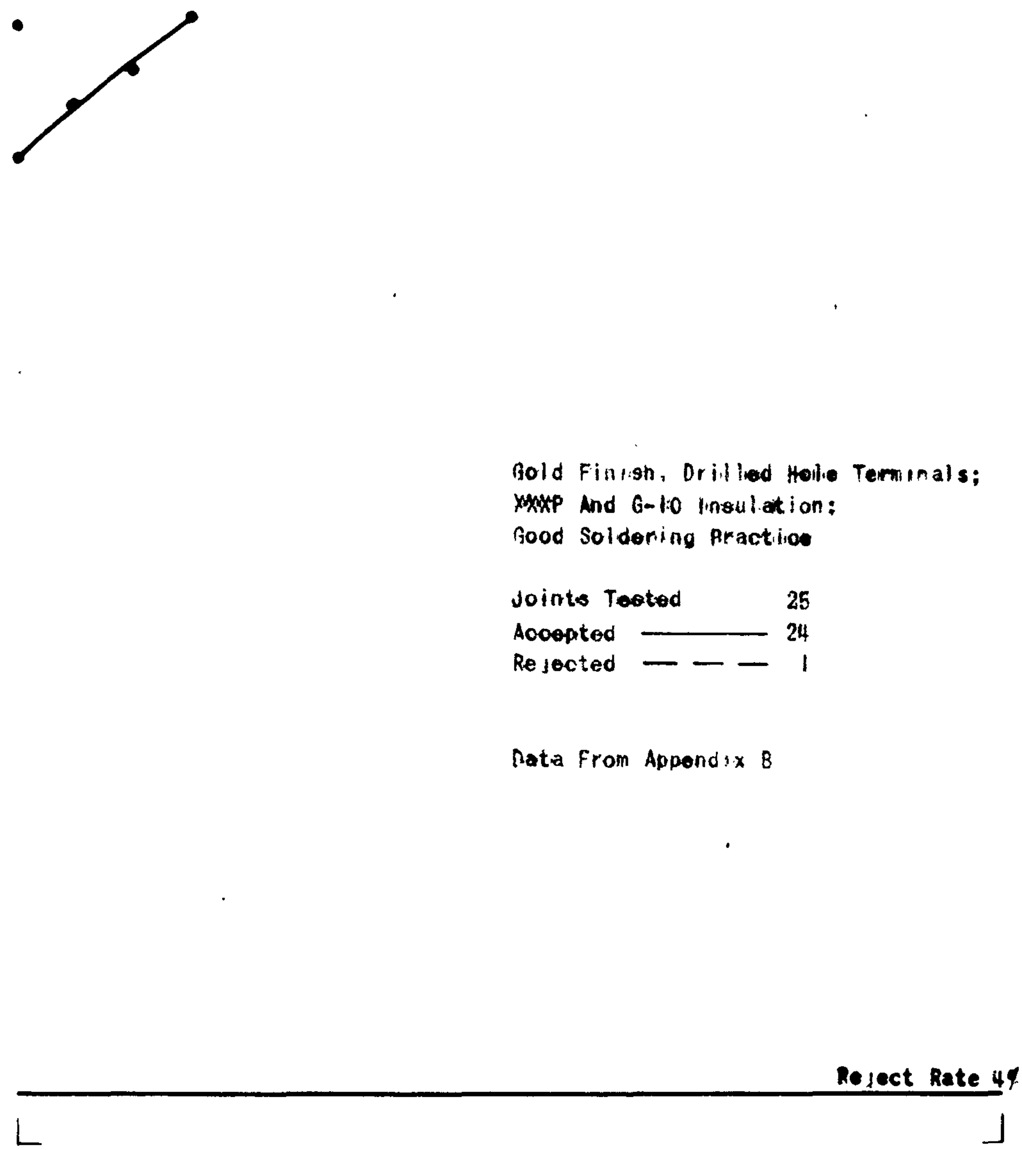
A limited amount of experimentation indicated that if the penetrant were applied with a brush exclusively to the wrap-around terminal and, if the soldering had been very carefully executed, extremely good joints would show no evidence of fluorescence whereas joints of slightly lower



Solder Finish, Drilled Hole Terminals;
XXXP And G-10 Insulation;
Good Soldering Practice

Joints Tested	40
Accepted ———————	37
Rejected — — —	3
Reject Rate	7.5%

Data From Appendix B


Gold Finish, Drilled Hole Terminals;
XXXP And G-10 Insulation;
Good Soldering Practice
Joints Tested 25
Accepted 24
Rejected 1
Data From Appendix B
Reject Rate 4%

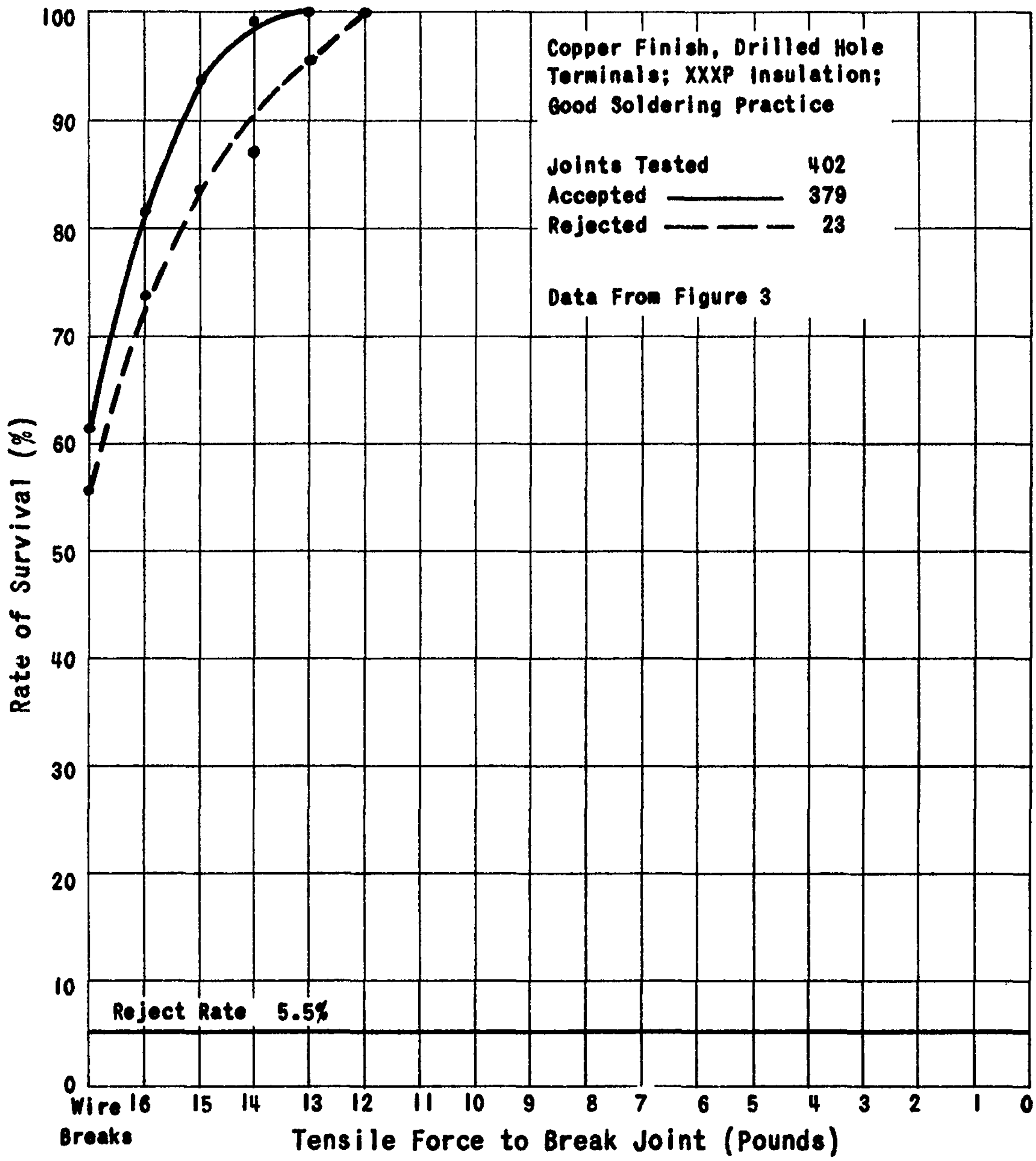


Figure 6. SUMMARY OF DATA TAKEN WITH VARIATIONS IN STANDARD TEST ASSEMBLY CONSTRUCTION; GOOD QUALITY JOINTS

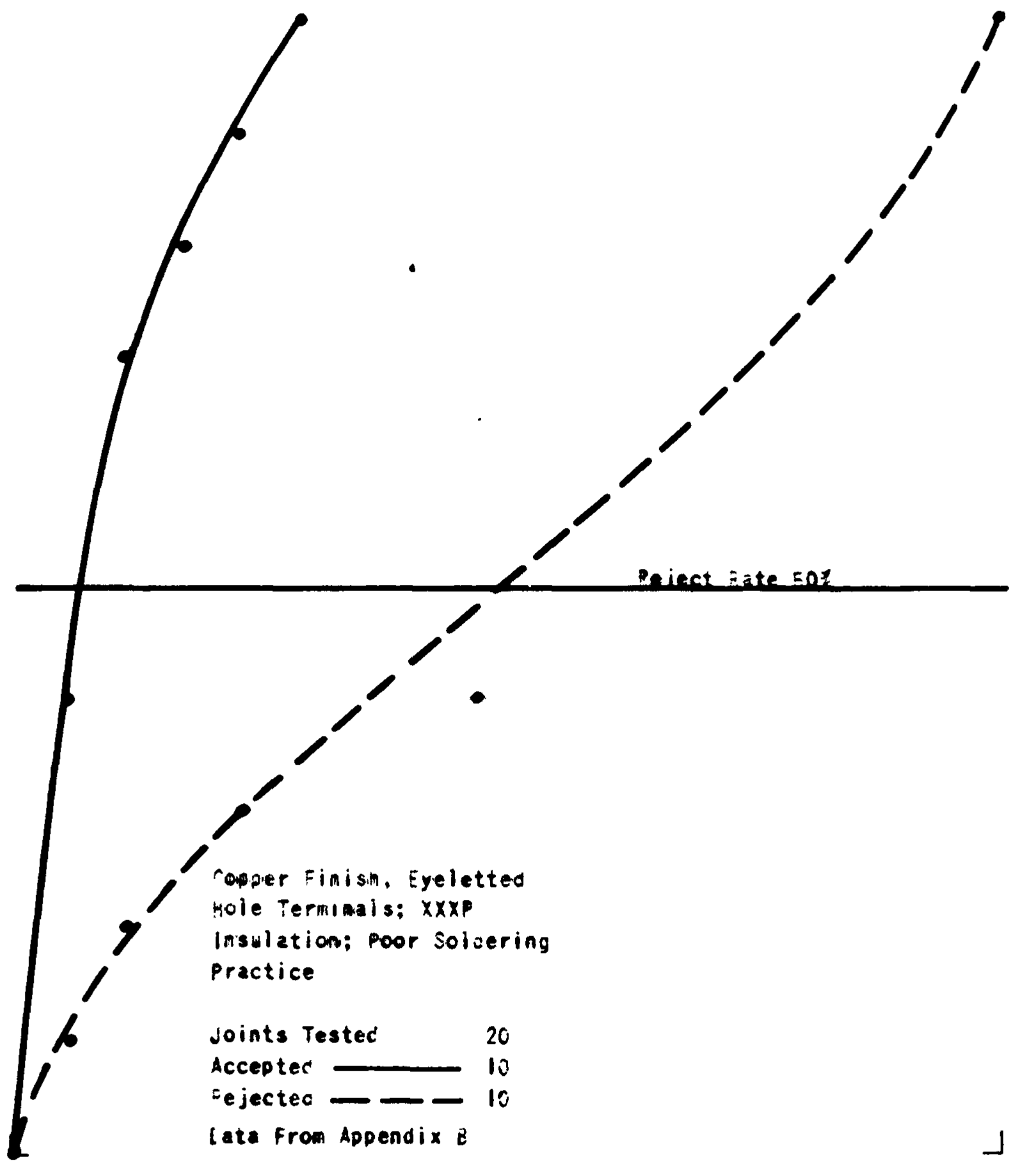
quality would fluoresce. The system might be used in this fashion when wrap-around terminals are involved to obtain a very high quality product, but it loses many of its natural advantages over ordinary visual inspection.

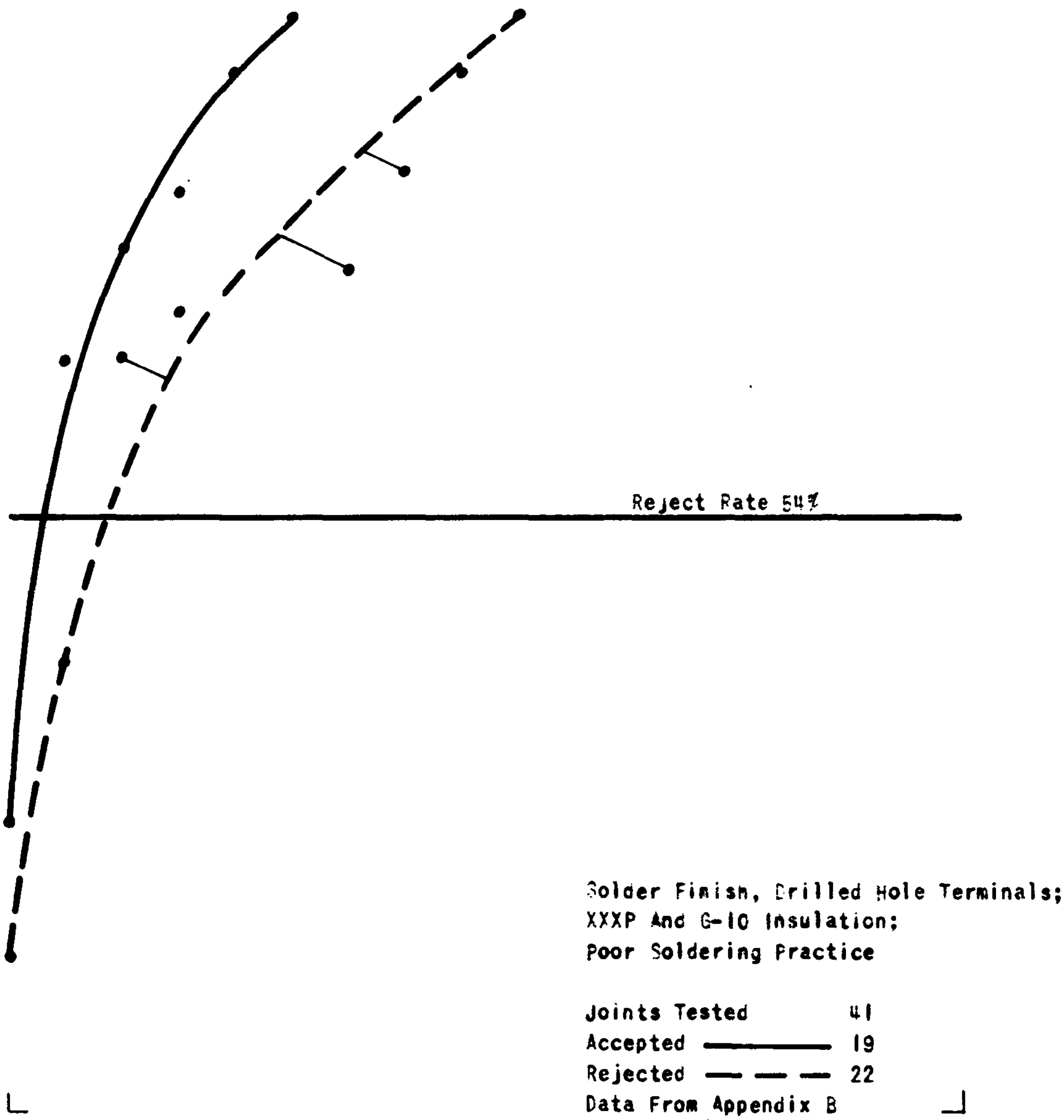
The data shown in Appendix B for the inspection of wrap-around joints indicate a rejection rate of 9% when good soldering practice was used and a rejection rate of 33% when the soldering practice was relatively poor. These values correlate well with the large amount of data obtained for plane surface joints. However, it should be noted that the quality determination for wrap-around joints required a certain amount of judgement, whereas the quality determination for plane surface joints was always made on a straight-forward go and no-go basis, depending on whether fluorescence was absent or present.

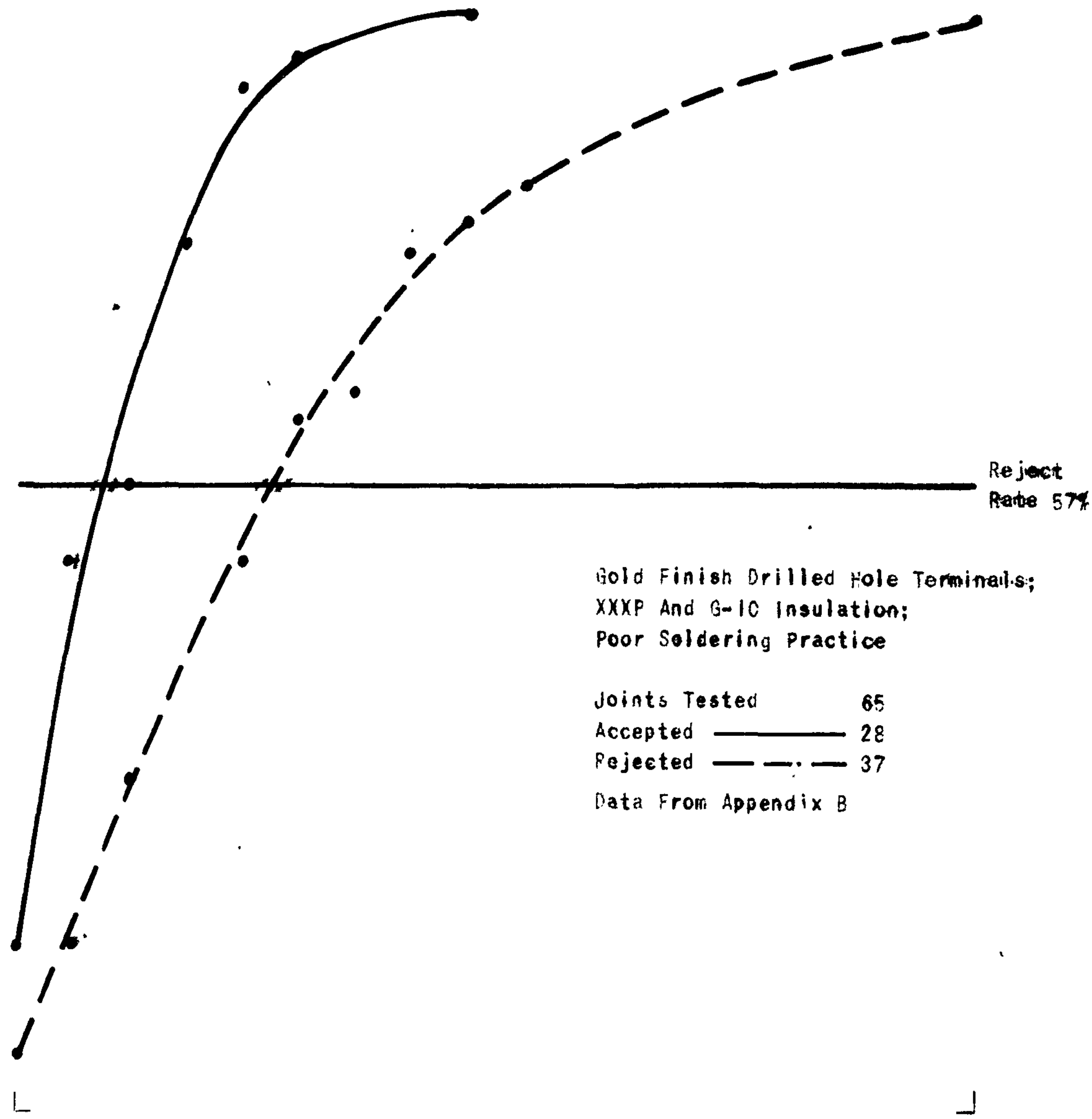
The physical strength data for wrap-around joints shown in Appendix B do not correlate with similar data taken for plane surface joints, since the wrap-around joint was in most cases mechanically stronger than the simulated component wire lead. If the inspection of wrap-around joints were to be further investigated, it would be necessary to devise a new physical test such as a peel test as a primary standard. Further work in this direction was not included in the program because of the time limitations of the contract.

2. Inspection of Random Commercial Assemblies

In order to obtain an indication of the universality of the penetrant system, small quantities of three kinds of commercial electronic


Reject Rate 50%
Copper Finish, Eyeletted
Hole Terminals; XXXP
Insulation; Poor Soldering
Practice
Joints Tested 20
Accepted 10
Rejected 10
Data From Appendix B


Reject Rate 54%
Solder Finish, Drilled Hole Terminals;
XXXP And G-10 Insulation;
Poor Soldering Practice
Joints Tested 41
Accepted 19
Rejected 22
Data From Appendix B


Reject Rate 57%
Gold Finish Drilled Hole Terminals;
XXXP And G-10 Insulation;
Poor Soldering Practice
Joints Tested 65
Accepted 28
Rejected 37
Data From Appendix B

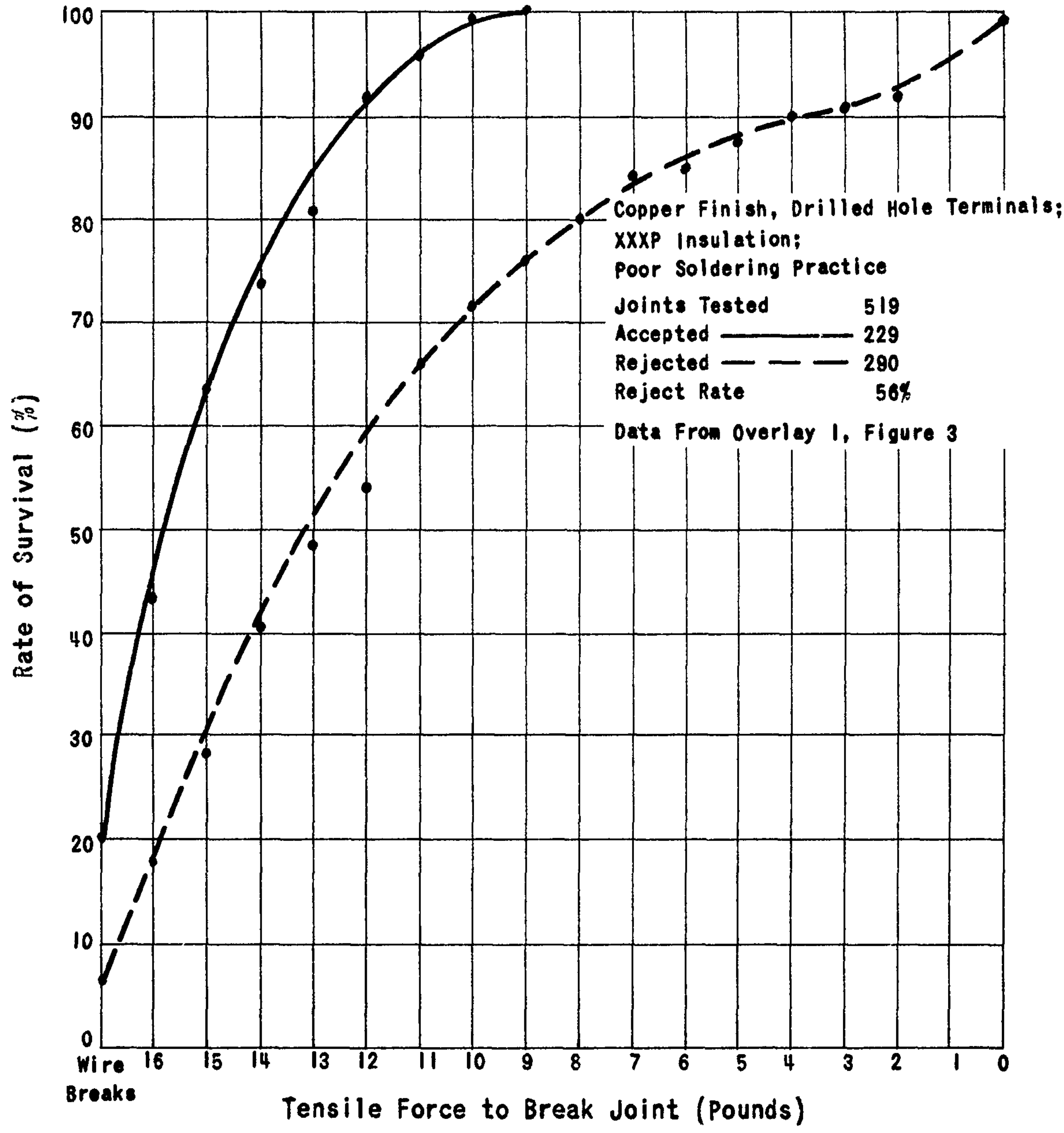


Figure 7. SUMMARY OF DATA TAKEN WITH VARIATIONS IN STANDARD TEST ASSEMBLY CONSTRUCTION; POOR QUALITY JOINTS

assemblies, all fabricated on printed circuit boards with through hole terminals, were inspected (See Figures 8, 9 and 10).

The first of these assemblies, shown in Figure 8, was a camera subassembly containing eight soldered joints. The joints were hand soldered in such a way that the wire ends were in many cases buried in the solder, preventing direct inspection of the bond between the wire lead and the solder by either the penetrant method or by normal visual methods. However, it was possible to evaluate the bond between the solder and board terminal and also determine the general quality of the joints by examining the solder surface condition.

One group of 98 of these camera subassemblies had been visually inspected and accepted in their normal manufacturing sequence before they were loaned for inspection by the penetrant method. Another group of 29 represented rejects accumulated during the normal manufacturing process. The results of the inspection with penetrant of both groups are summarized in Table I, page 47. No problems were encountered during the performance of this inspection. The percentage of "defective" joints correlated well with the previous findings of the manufacturing department. It is interesting to note that the penetrant system detected a relatively large number of circuit board mechanical defects other than soldered joint defects. It is believed that the responsible manufacturing department was unaware of the board defects prior to the penetrant system test.

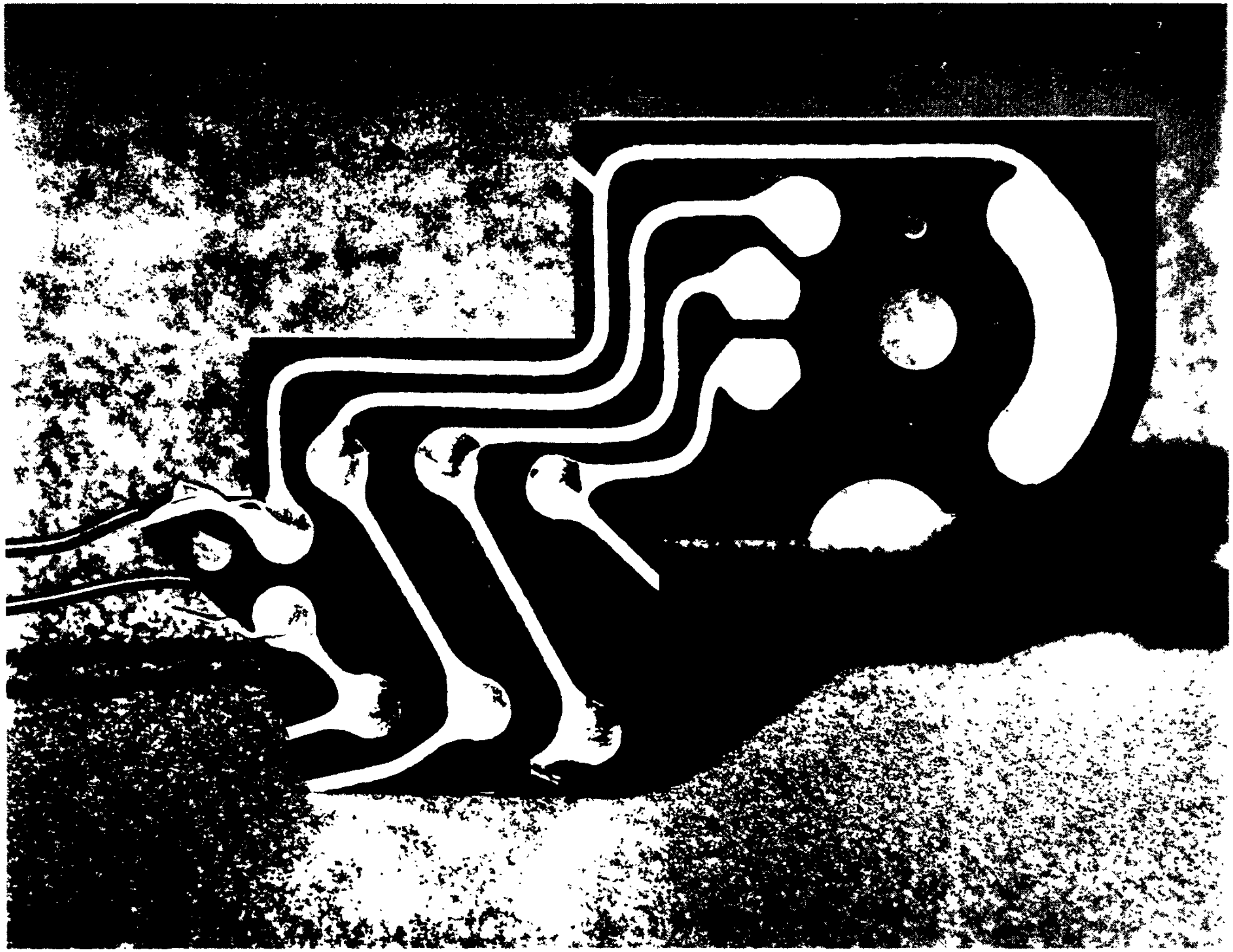


Figure 8. CAMERA PRINTED CIRCUIT SUBASSEMBLY

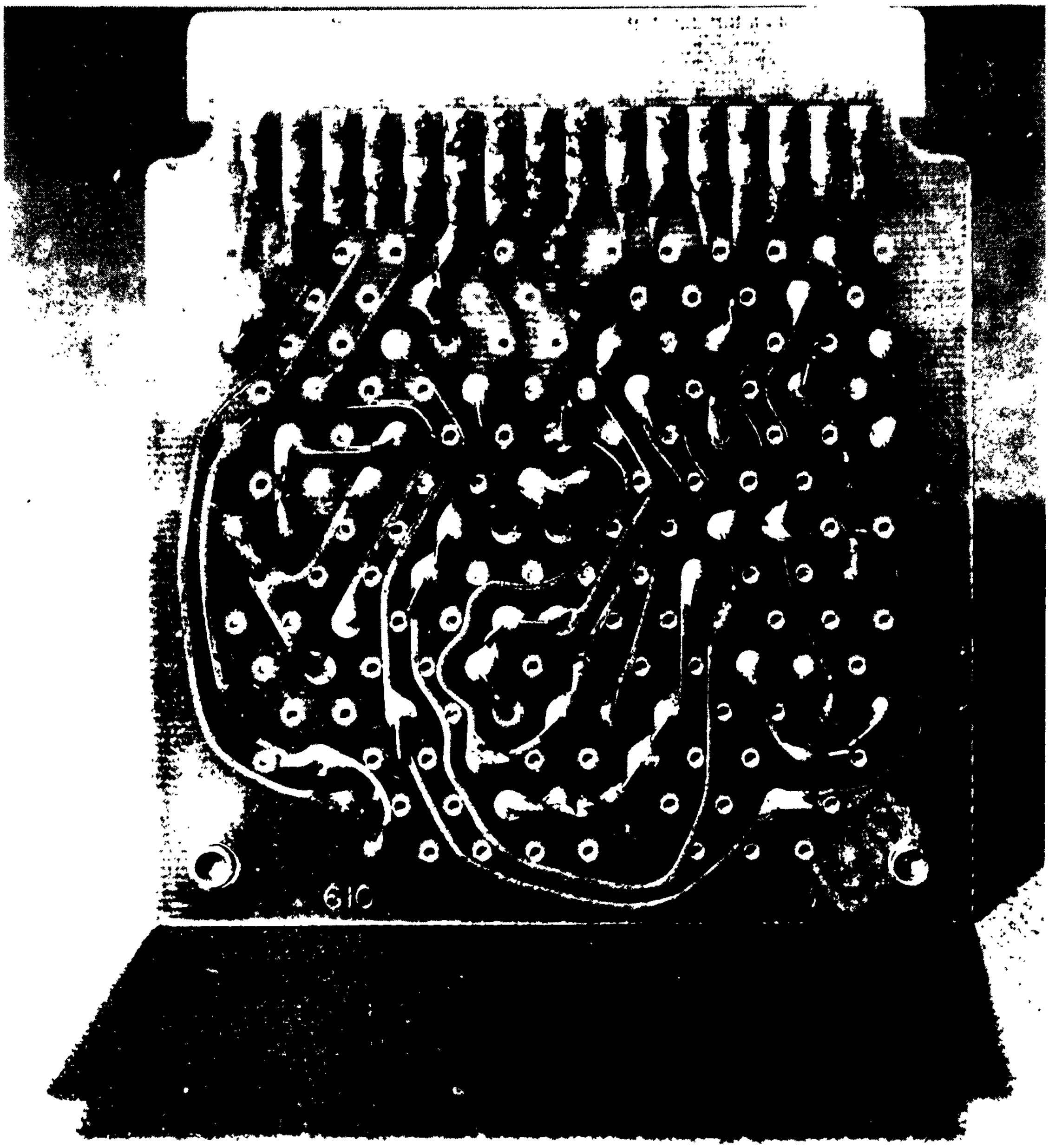


Figure 9. TELEPHONE SWITCH GEAR SUBASSEMBLY, 3" X 3"

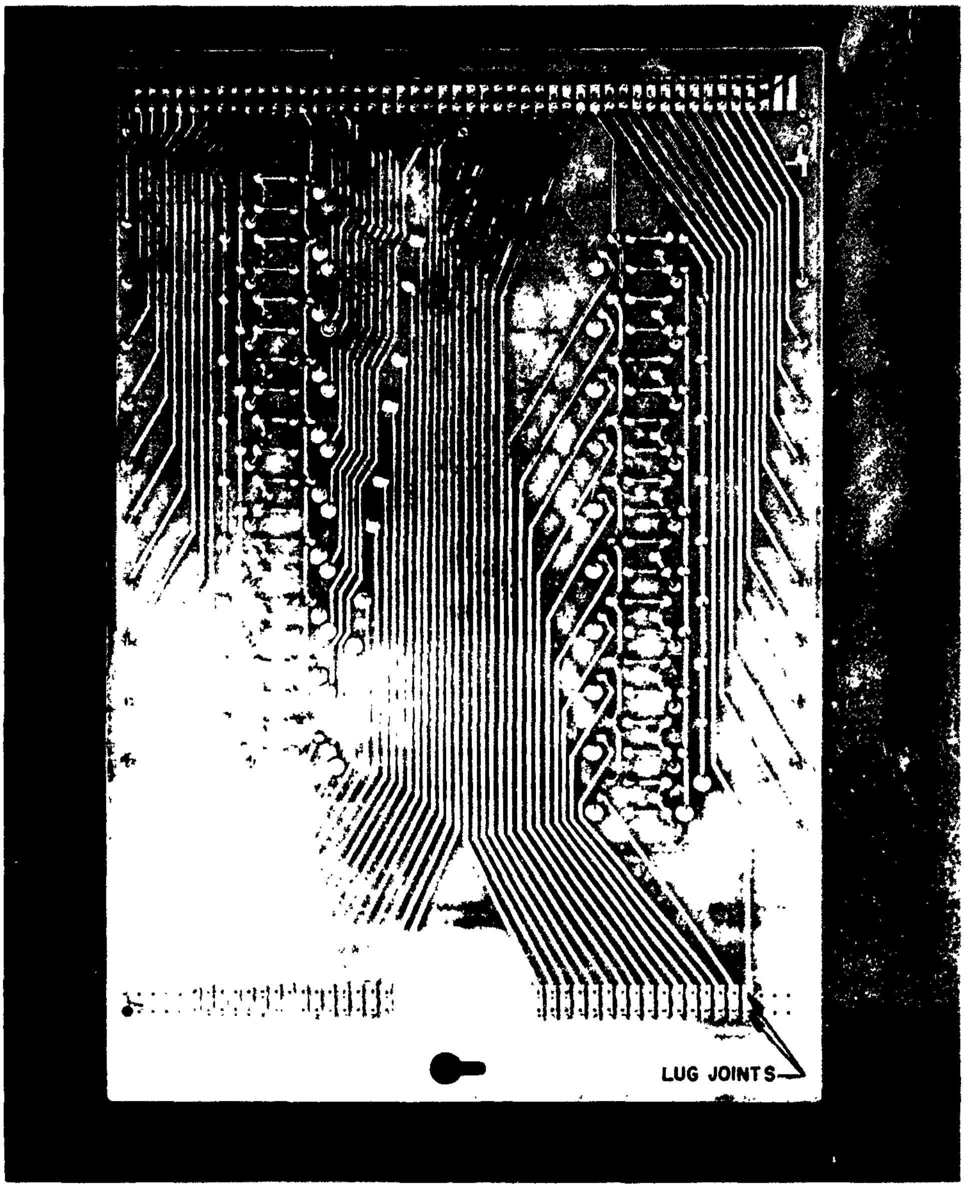
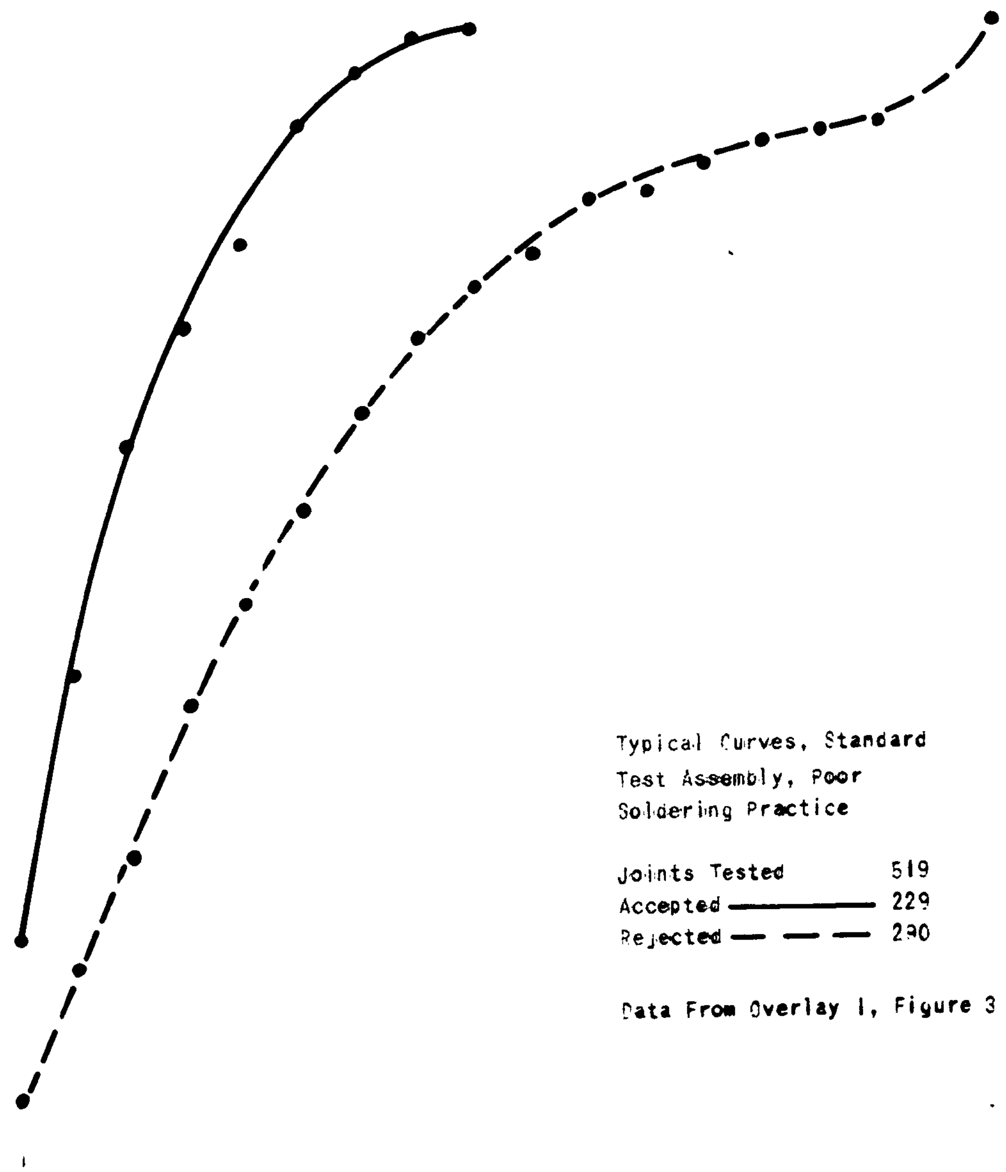


Figure 10. TELEPHONE SWITCH GEAR SUBASSEMBLY, 8" X 12"

Physical strength data were taken at random on 58 of the joints in the group of 29 camera subassemblies that were manufacturing rejects and therefore could be destroyed. The results are given in Appendix C and summarized in Figure 11. The curves shown in the figure for these commercial assemblies correlate very well with those shown for standard laboratory assemblies that were fabricated during system development under conditions representing poor soldering practice.

The second of the three types of commercial assemblies used to evaluate the penetrant system is shown in Figure 9. It is a three-inch by three-inch subassembly for use in telephone switch gear. Various models were supplied that contained anywhere from 50 to 97 dip-soldered joints each. The joints were ideally suited for inspection by ordinary visual methods or by the penetrant method, since all of the joint members extended to or through the solder surface. Inspection of ten assemblies with penetrant was accomplished without encountering problems of any kind. The results are summarized in Table I, page 47 and more detail is given in Appendix C. These findings could not be checked by physical tests since the assemblies could not be destroyed, but very careful visual examination of joint samples under high power magnification at least verified that the penetrant system had accurately detected significant surface defects.


Typical Curves, Standard
Test Assembly, Poor
Soldering Practice
Joints Tested 519
Accepted 229
Rejected 290
Data From Overlay I, Figure 3

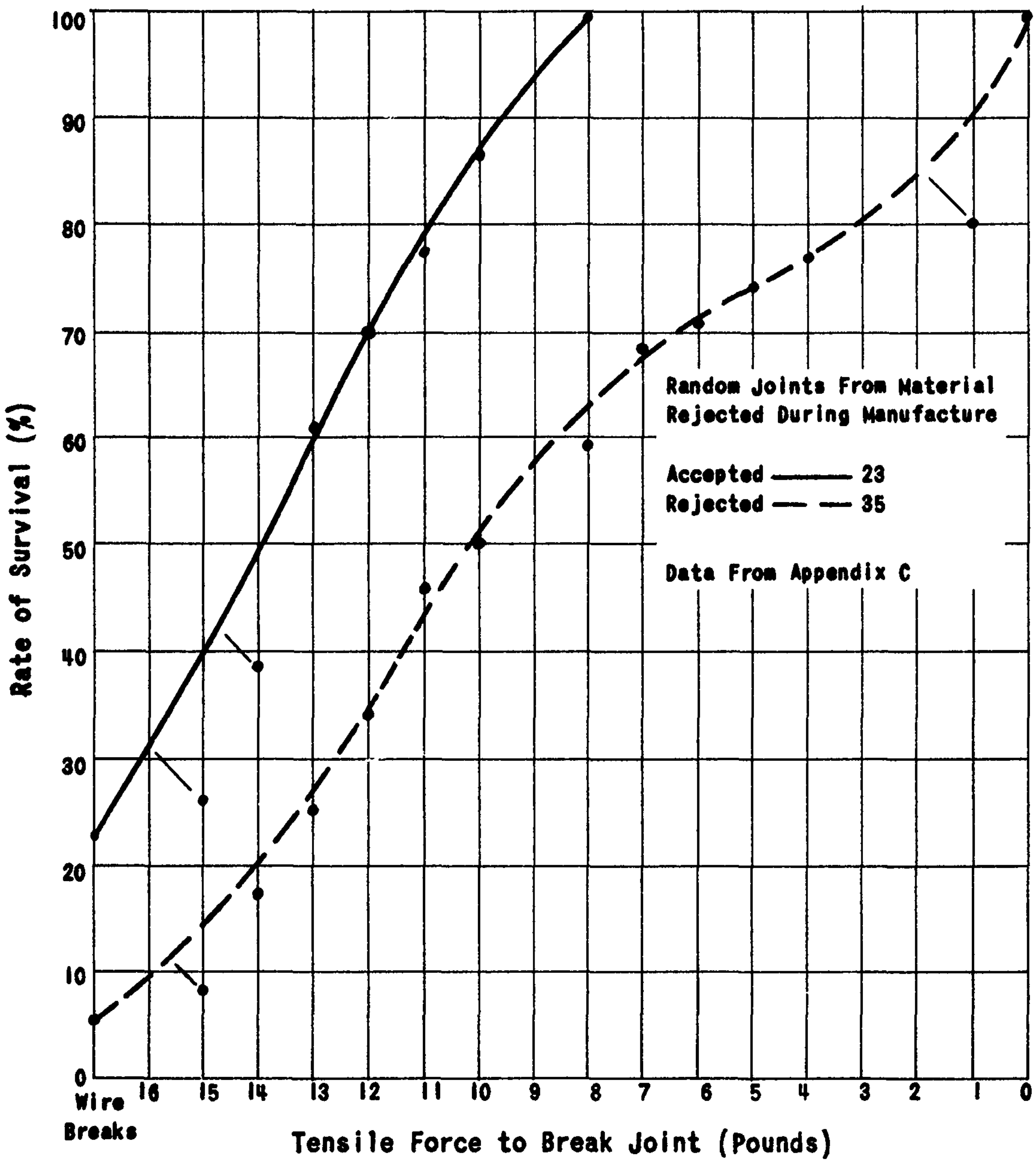


Figure 11. JOINT QUALITY ON COMMERCIAL ASSEMBLY (Figure 8) DETERMINED BY THE PENETRANT PROCESS VERSUS PHYSICAL STRENGTH

The third commercial assembly examined was the eight-inch by twelve-inch unit with 402 dip soldered joints shown in Figure 10. It was also a telephone switch gear subassembly. Again, all joining members extended to or through the solder surface and the inspection with penetrant was accomplished without difficulty. It was found, that sixteen assemblies, representing 6,432 joints, could be inspected by one operator in one hour, including the time required to prepare the work by applying penetrant, etc., and the time required to mark the rejected joints with a wax pencil. This rate could undoubtedly be improved with practice.

Detailed results of the inspection are shown in Appendix C and summarized in Table I. The data are broken down to differentiate between the "lug joints", identified in Figure 10, and the remaining "wire joints". In the former, the joining members were the circuit board terminals and the lugs of terminal clips and, in the latter, the joint was between the board terminals and component wire leads. Again, the results of the inspection with penetrant could not be checked by physical tests because the samples could not be destroyed, but visual examination of a percentage of joints under high

TABLE I DATA SUMMARY, COMMERCIAL ELECTRONIC ASSEMBLIES

Camera Assembly, Figure 8

Quantity	Manufacturing Status	Total Number of Joints	Number of Joints Rejected	% Joints Rejected	Number of Circuit Board Defects
98	Accepted	784	6	0.76	16
29	Rejected	232	46	20.0	15

Telephone Switch Gear Assembly, 3" X 3", Figure 9

Quantity	Total Number of Joints	Number of Joints Rejected	% Joints Rejected	Number of Circuit Board Defects
10	805	21	2.6	1

Telephone Switch Gear Assembly, 8" X 12", Figure 10

Quantity	Total Number of Wire Joints	Number of Wire Joints Rejected	% Wire Joints Rejected	Total Number of Lug Joints	Number of Lug Joints Rejected	% Lug Joints Rejected	Number of Circuit Board Defects
27	6750	150	2.2	4104	1957	47.5	4

power magnification verified that the penetrant had accurately detected surface flaws.

While imminent expiration of the contract term limited the testing of the penetrant inspection system on commercial assemblies to those discussed, the work accomplished gives confidence that the system is directly applicable to current manufacturing activities and will reduce costs and improve product reliability.

B. STUDY OF THE EFFECTS OF VIBRATION ON INSPECTED MATERIAL

Previous progress reports discussed tests in process to make certain that soldered joints accepted by the penetrant inspection system were of sufficiently high quality to survive the vibration that might be encountered in military usage. This evaluation was completed during the current report period. In order to completely review the test program for the convenience of the reader, some data that appeared in earlier reports reappears herein.

The entire accumulation of detailed data is given in Appendix D. In general, several tests were performed wherein a lot of standard assemblies was manufactured; the joints were inspected by the penetrant process; the lot was vibrated and, finally, the physical strength of each joint was measured. The effects of vibration were evaluated by comparing the joint quality predicted by the penetrant inspection process before vibration against the physical strength of the joint after vibration.

In some tests, a portion of the lot was used as controls which were subjected to the entire test procedure except that vibration was omitted. It was thereby possible to compare the predicted quality and physical strength data taken for the controls with the similar data taken for the vibrated assemblies.

The standard assembly described in Appendix A was used throughout the investigation. It always contained the phenolic circuit board and plain copper, drilled-hole terminals specified in the appendix as one of several alternates. Vibration testing was performed according to the methods given in Appendix A, except that in some cases, more than one of the standard cycles were used. The physical test employed was always the standard tensile pull test described in the appendix.

Figure 12 summarizes the data for a group of joints made under conditions typical of good soldering practice and vibrated for one standard cycle at an ambient temperature of 75°F. Similar data for joints made under conditions typical of very poor soldering practice are shown in Figure 13. Controls were used in each of these tests. It so happened that all of the joints made under good soldering practice were accepted by the penetrant inspection process and all of the joints made under poor soldering practice were rejected. It can be seen that the post vibration physical strength of all of the accepted joints was excellent and that the post vibration strength of a high percentage of the rejected joints was poor. It can also

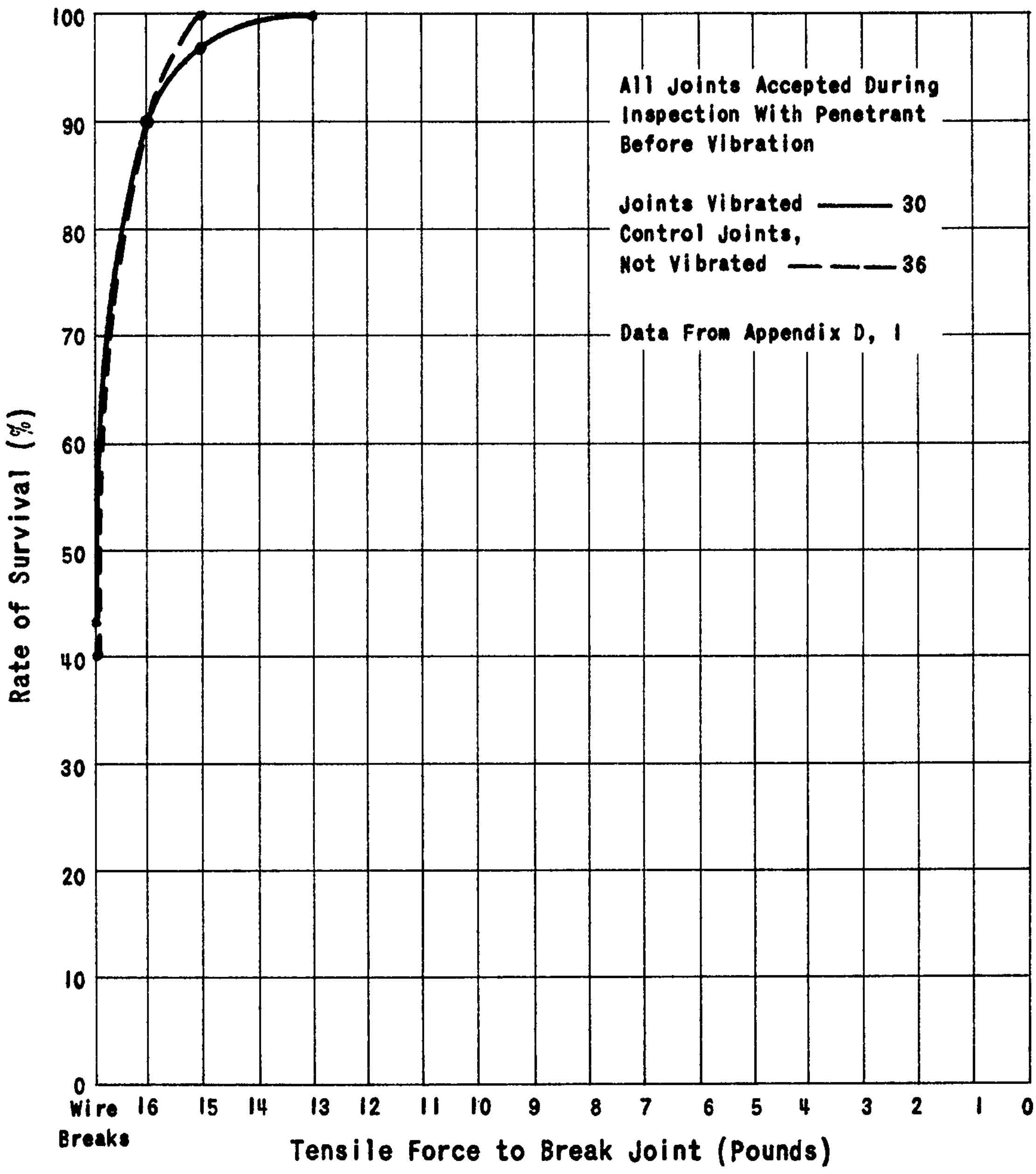


Figure 12. VIBRATION TESTING OF GOOD QUALITY SOLDERED JOINTS AT 75° F

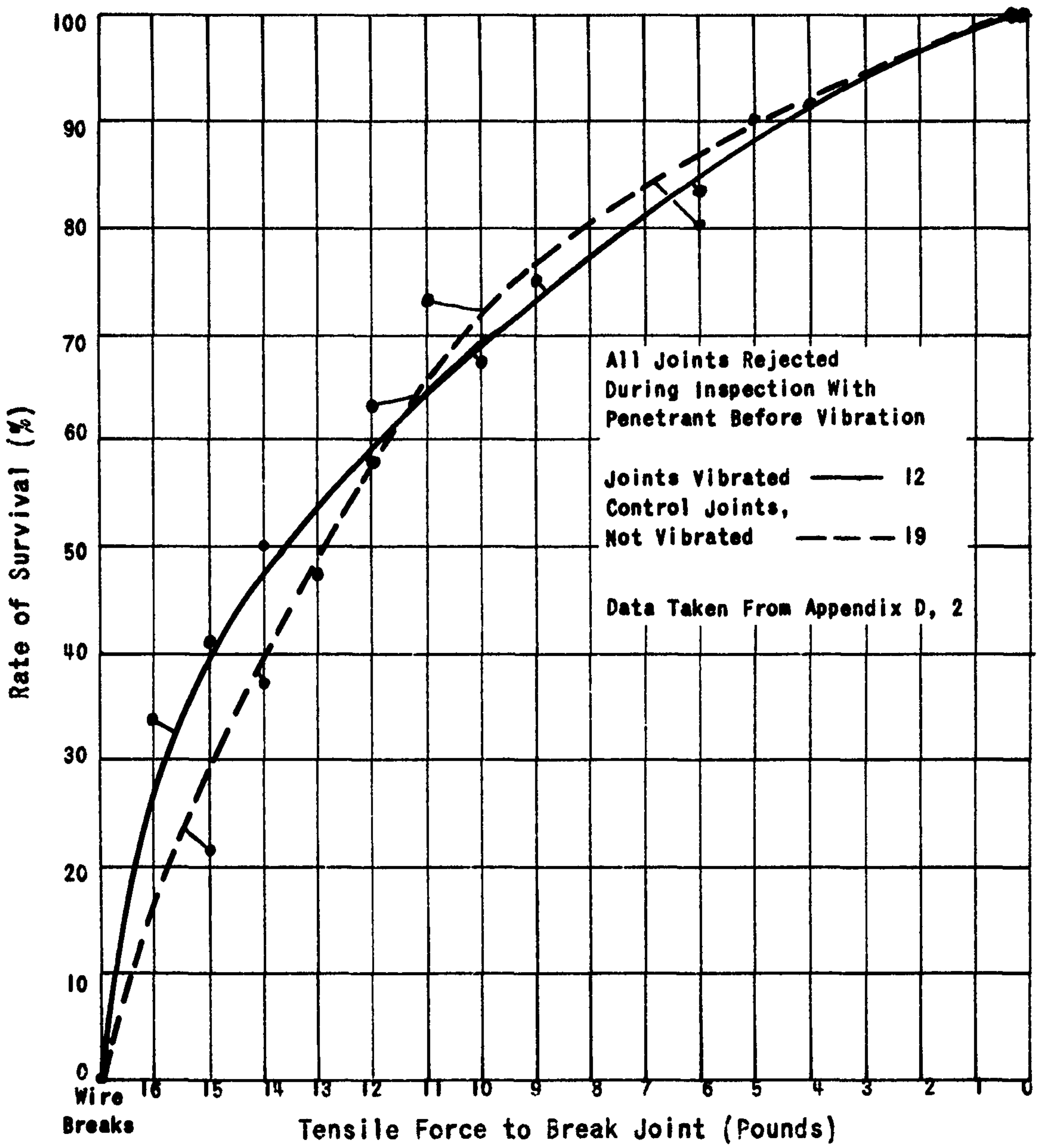


Figure 13. VIBRATION TESTING OF POOR QUALITY SOLDERED JOINTS AT 75° F

be seen that the control joints exhibited the same characteristics as the vibrated joints during physical testing. It can be concluded that, at least for the electronic assembly design tested, joint quality as determined by the penetrant inspection process does not change as the result of exposure to severe vibration at an ambient temperature of 75°F.

Figure 14 summarizes data for twenty-four joints prepared under conditions typical of good soldering practice and vibrated for one standard cycle at ambient temperatures of either -65°F or +165°F. No controls were used. All joints except one were accepted by the penetrant inspection process before vibration and all exhibited good physical strength after vibration. The one joint rejected during inspection was consistent with the normal rejection rate expected for high quality joints. It was concluded that, for the assembly construction tested, joints accepted by the penetrant process will withstand severe vibration at ambient temperatures of -65°F and +165°F.

In figure 15 is shown the results of a test of a small number of joints of random quality that were vibrated through a random number of standard cycles up to three, and temperatures of either -65°F or +75°F. The exact history of each joint can be determined by referring to the information given in Appendix D, Part 4. No controls were used in this test. The minimum physical strength of the joints accepted by the penetrant inspection process was found to be good after vibration and the average physical strength

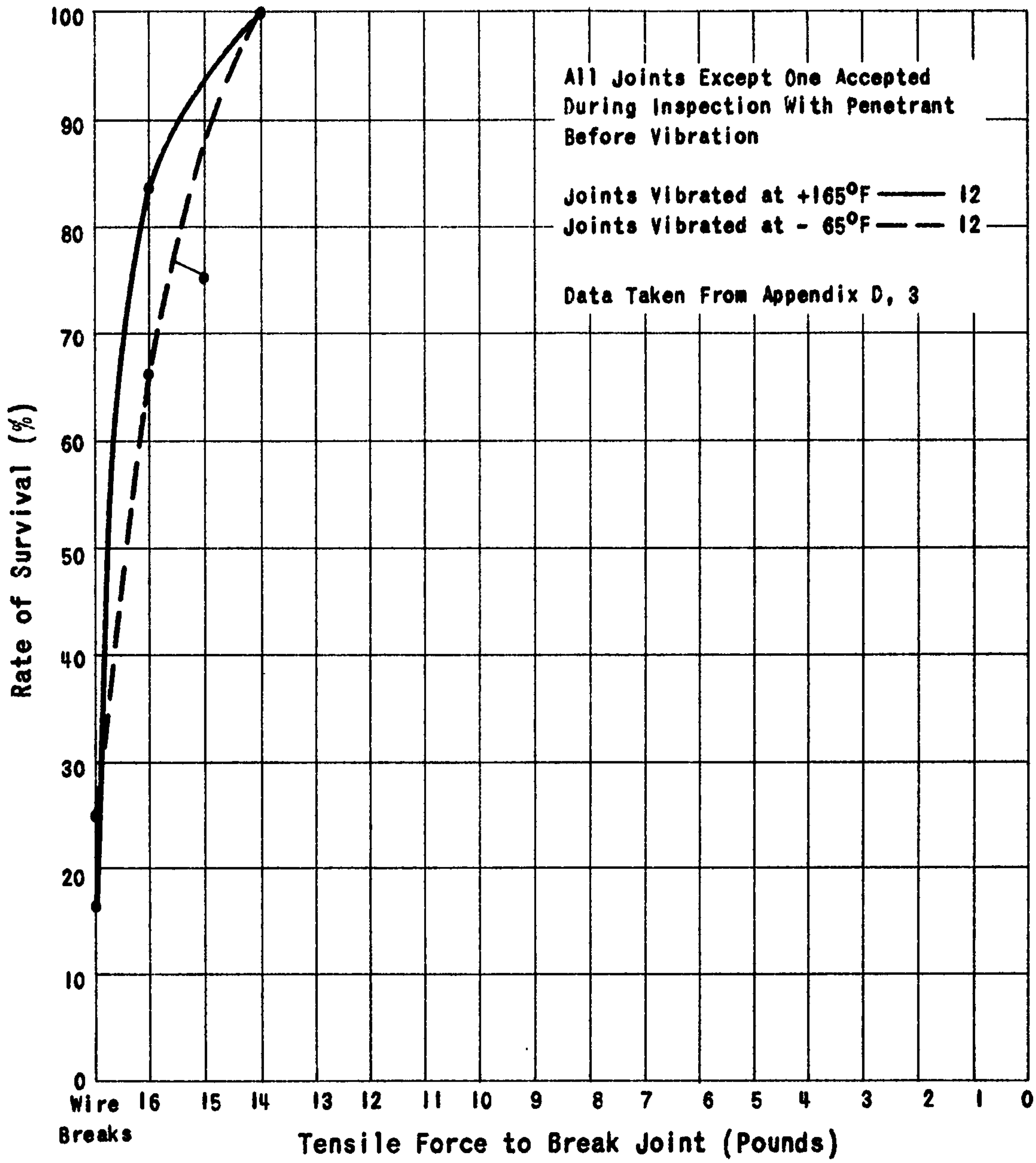


Figure 14. VIBRATION TESTING OF GOOD QUALITY SOLDERED JOINTS AT −65° F AND +165° F

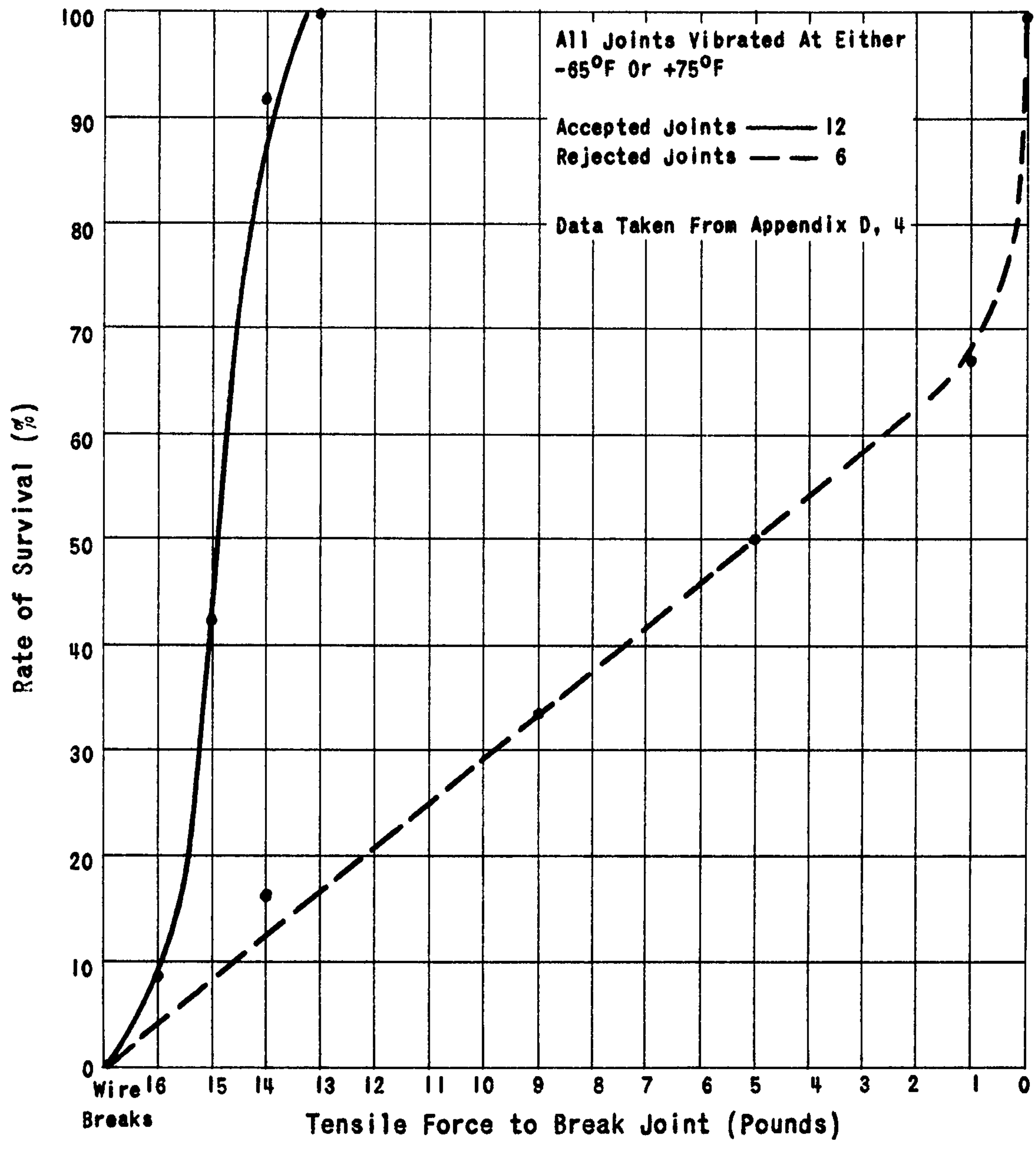


Figure 15. SEVERE VIBRATION TESTING OF RANDOM QUALITY SOLDERED JOINTS AT −65° F AND +75°F

of the group rejected by the penetrant process was poor after vibration. These results confirmed that, for the assembly design tested, a soldered joint accepted by the penetrant process will withstand very severe vibration at temperatures of -65°F and +76°F.

During the performance of the test just described, an inspection with penetrant was arbitrarily made after each standard vibration cycle. In a few cases, these successive inspections did not yield the same results; i.e., a joint might be accepted at the first inspection, be subjected to a vibration cycle and appear as a reject when again inspected. Partial data of this type gathered during the preceding report period led to a statement in the third quarterly report that joints made under conditions typical of poor soldering practice but accepted by the penetrant inspection process, may fail during vibration at cold temperatures. It is now concluded that the failure to obtain identical results in a few cases during successive inspections merely indicated a joint of marginal quality. In support of this conclusion, it is pointed out that all of the joints which exhibited this characteristic were made under conditions typical of poor soldering practice and, therefore, should be expected to be of marginal quality.

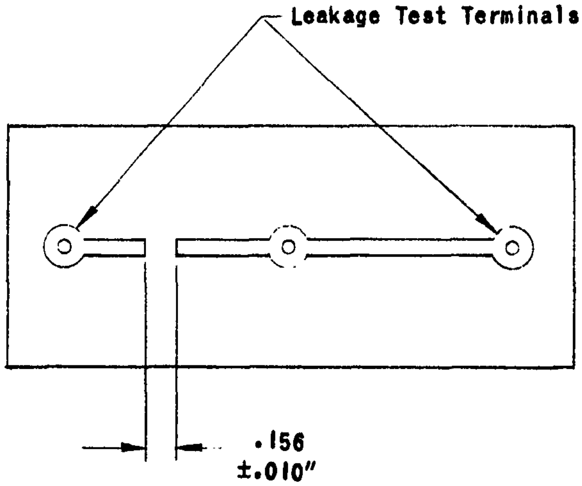
C. STUDY OF THE EFFECTS OF SYSTEM CHEMICALS ON PRODUCT PERFORMANCE

At the very start of the development of the penetrant inspection process, preliminary tests were performed to make sure that the basic materials employed would not be obviously detrimental to electrical products. The only harmful effect observed during the entire first three quarters of the project was that the trichlorethylene used in the process attacked certain inks that might be employed to label commercial assemblies. During the final report period, more thorough investigations were made to determine if the inspection process as finally developed might cause harmful electrical leakage or might have a corrosive effect on electrical assemblies.

To investigate electrical leakage, the standard test assembly described in Appendix A was modified as shown in Figure 16. The circuit boards in the modified assemblies used XXXP phenolic insulation.

Electrical leakage was measured on seven of the special purpose test assemblies after they had been stabilized in a 46% relative humidity atmosphere at 75°F. They were then put through the penetrant inspection process and electrical leakage measurements were immediately made on four out of the seven units in a 46% RH, 75°F atmosphere. The remaining three were stored in a 95% RH, 75°F atmosphere and leakage measurements were made after 24-hour and 96-hour storage intervals. Data obtained during the test are shown in Table II (Page 58). It was concluded that subjecting the assembly to the penetrant process did not alter its electrical leakage characteristics.

As a further check, four of the seven test assemblies were thoroughly cleaned with trichlorethylene and the leakage path was successively bridged with trichlorethylene, developer powder, and penetrant while resistance measurements were taken. The data, shown in Table II, indicate that none of these materials which are basic to the penetrant inspection process should



NOTE: This Modification of the Assembly Described in Appendix A Includes the Alternate Circuit Board Containing XXXP Phenolic Insulation and Plain Copper, Drilled Hole Terminals.

Figure 16. STANDARD TEST ASSEMBLY MODIFIED FOR ELECTRICAL LEAKAGE MEASUREMENTS

TABLE II DATA, ELECTRICAL LEAKAGE TESTS

Assembly No.	Leakage Before Inspection with Penetrant; 75°F, 46% RH (Megohms)	After Minimum Delay at 75°F, 46% RH (Megohms)	After 24 Hours Storage at 75°F, 95% RH (Megohms)	After 96 Hours Storage at 75°F, 95% RH (Megohms)
1	>1000K	>1000K	—	—
2	1000K	>1000K	—	—
3	>1000K	1000K	—	—
4	>1000K	>1000K	—	—
5	>1000K	—	>1000K	>1000K
6	>1000K	—	>1000K	>1000K
7	>1000K	—	>1000K	1000K

Notes to this table on following page.

(Cont'd.)

TABLE II (Cont'd)

Assembly No.	Leakage After Cleaning; 75°F 46% RH (Megohms)	Leakage with Pure Trichlor-ethylene across Gap (Megohms)	Leakage after 3 Minute Air Dry (Megohms)	Leakage with Developer Powder Across Gap (Megohms)	Leakage with Penetrant Across Gap (Megohms)	Leakage After Normal Trichlor-ethylene Wash (Megohms)
1	>1000K	31K	1000K	>1000K	600K	>1000K
2	>1000K	24K	1000K	>1000K	900K	>1000K
3	1000K	24K	1000K	>1000K	1000K	>1000K
4	>1000K	25K	1000K	>1000K	900K	>1000K

NOTES: 1. Measurements taken using special test assembly, Figure 16.

2. All resistance readings taken at a test potential of 105 volts, D.C.

cause electrical leakage problems. It is pointed out that the relatively low resistance path exhibited by the penetrant was a temporary condition that was corrected during the normal operation of removing the excess penetrant with a trichlorethylene wash.

The possible corrosive effect of the penetrant was checked. Eight trichlorethylene washed, good quality, Code II-A-3, soldered joints were prepared on standard test assemblies described in Appendix A. These contained phenolic circuit-board insulation and plain, copper, drilled hole terminals. The test assemblies were immersed in Magnaflux Compound Type ZL-22 in a 95% RH, 160°F atmosphere for approximately three months. The joints were examined visually and by the penetrant process during this interval (1/15, 1/17, 1/22, 2/23, 3/20 and 4/11/62) to determine if the solder surface finish had roughened or deteriorated in a manner indicative of corrosion. The joints were eventually destroyed by the standard tensile pull test described in Appendix A.

No visible evidence of corrosion was detected. It was noted that the average physical strength of the joints was less than had been established as normal throughout the program.

Joint No.	Pull to Failure	Joint No.	Pull to Failure
1	13.4 pounds	5	14.5
2	13.8	6	12.0
3	15.2	7	13.8
4	12.4	8	13.3

It is not believed that this change was a result of corrosion caused by the sustained presence of penetrant on the test joints. It is pointed out that the physical strength of all joints was satisfactorily high at the end of the test.

D. INVESTIGATION OF OPERATOR HEALTH HAZARDS

Qualified medical sources advise that the liquids and powder used in the penetrant inspection process do not involve any danger or health hazards provided that normal industrial safety precautions are taken. These would involve forced air ventilation to remove penetrant vaporized by spraying, vaporized tricholorethylene resulting from spraying and evaporation, and free particles of developer powder that may escape into the air. To prevent skin allergies, rubber gloves should also be provided for the operations of spraying the penetrant and trichlorethylene.

The greatest hazard is the danger of exposure to the toxic fumes of trichlorethylene. The April, 1961, volume of the American Conference of Governmental and Industrial Hygenist stated that ventilation for trichlorethylene should be adequate to limit concentration in the air breathed by the operator to a maximum of 520 milligrams per cubic meter of air.

E. DESIGN AND CONSTRUCTION OF A PROTOTYPE INSPECTION APPARATUS

It was reported at the end of the third quarter that preliminary designs for a typical apparatus required for the penetrant inspection process had been started and certain parts of the apparatus had been constructed. During the final report period, designing and fabrication were completed and the apparatus was used to perform a limited amount of the testing reported herein.

A complete description of the equipment is given in Section II, Part C (see page 23). This prototype is intended only to demonstrate a general arrangement of the basic facilities required and obviously can be modified to suit particular manufacturing plant arrangements and particular types of work. It is significant that it can be assembled at low cost from ordinary commercial items commonly found in manufacturing plants.

The prototype will be shipped to Frankford Arsenal, together with design drawings, where it is understood that it will be available for demonstration and experimentation.

APPENDIXES

APPENDIX A

STANDARDS ESTABLISHED FOR THE EVALUATION OF A PROCESS TO INSPECT SOLDERED ELECTRICAL JOINTS

Parameter		Specification	Identification Code*
1. Terminal Board			
A. Material	a.	.06-inch thick, XXXP phenolic, laminated on one face with .0015-inch thick copper foil.	None
	b.	.062-inch thick, G-10 glass fiber and epoxy resin, laminated on one face with .0015-inch thick copper foil.	None
B. Configuration		See Figure A 1	--
C. Circuitry		Formed by etching	--
D. Terminal Style	a.	.034-inch diameter drilled hole.	None
	b.	Brass eyelet, Figure A 2, riveted into .052-inch diameter drilled hole.	None
	c.	Wrap-around terminal, Figure A 3, riveted into drilled hole.	None
E. Terminal and Circuitry Finish	a.	Copper or copper plated.	None
	b.	Solder plated.	None
	c.	Gold plated.	None

* See note on final page of appendix for explanatory discussion of identification code.

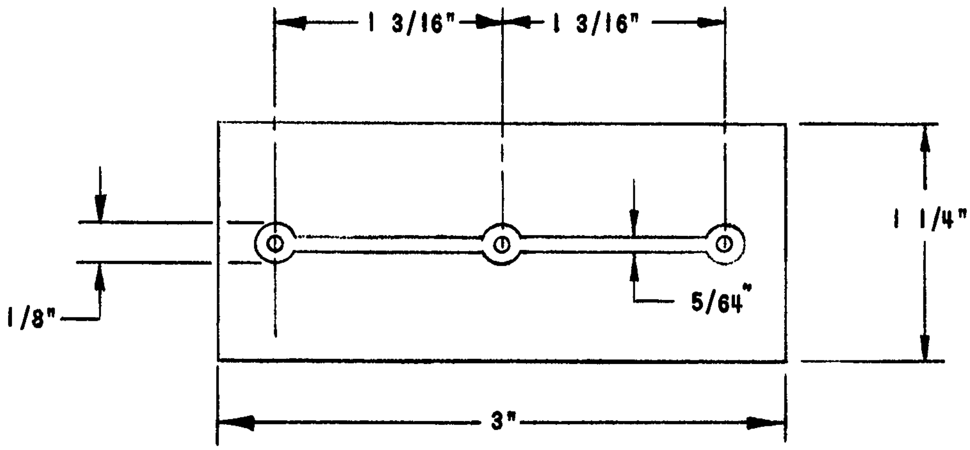


Figure A1. TERMINAL BOARD CONFIGURATION

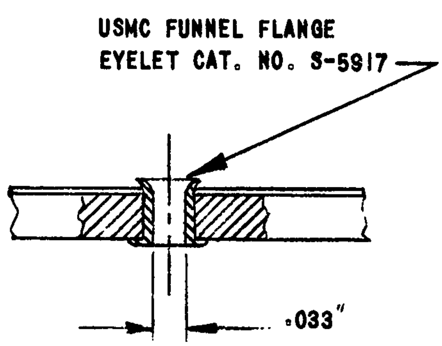


Figure A2. BRASS EYELET

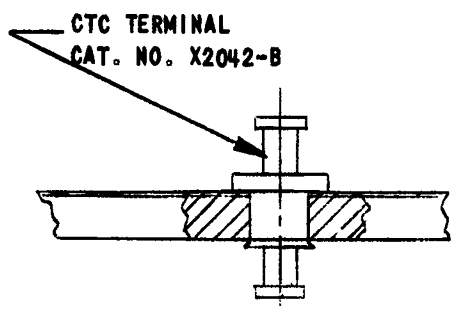


Figure A3. WRAP-AROUND TERMINAL

APPENDIX A (Cont'd.)

Parameter		Specification	Identification Code*
2. Simulated Component		Number 22 gage (.025-inch diameter) tin plated, copper wire.	--
3. Mechanical Joint		For plain hole and eyeletted hole circuit board terminations, wire is inserted from insulated side of board and projects approximately 5/32-inch above the circuit side of board. For wrap-around terminal board terminations, wire is placed in terminal groove and wrapped around terminal for a minimum of one and a maximum of two turns.	--
4. Joint Cleanliness	a.	Circuit board terminals and simulated component terminals thoroughly wiped with trichlorethylene.	A
	b.	Circuit board terminals contaminated with a thin coating of silicone grease (Dow Corning High Vacuum Silicone Lubricant) applied with the finger tips. Simulated component terminals thoroughly wiped with trichlorethylene.	B

APPENDIX A (Cont'd.)

Parameter	Specification	Identification Code*
	c. Circuit board terminals thoroughly wiped with trichlorethylene. Simulated component terminals contaminated with a thin coating of silicone grease applied with the finger tips.	C
	d. Circuit board terminals "oxidized" by baking for 36 hours at a temperature of 175°F in an oxygen atmosphere at 100% relative humidity. Simulated component terminals thoroughly wiped with trichlorethylene.	OX
5. Solder	60% Tin, 40% Lead.	--
6. Soldering Flux	Activated resin, BuOrd Drawing 701329 (300 grams cyclohexanol, 100 grams polypal resin, 100 grams benzoic acid)	--
7. Fluxing Procedure	Apply flux to joint area with small artist's "camel hair" brush.	--

APPENDIX A (Cont'd.)

Parameter		Specification	Identification Code*
8. Soldering Technique			
A. Apparatus		See Figure A 4	--
B. Fixturing		See Figure A 5	--
C. Solder Temperature	a.	450°F	I
	b.	600°F	II
D. Dwell Time in Molten Solder	a.	1/4 second	0
	b.	1/2 second	1
	c.	3/4 second	1A
	d.	1 second	2
	e.	2 seconds	3
9. Physical Tests			
(Primary Standards)			
A. Tensile			
a. Apparatus		See Figure A 6	--
b. Fixturing		See Figure A 7	--
c. Method	a.	Pull from insulation side and record force in pounds required to cause joint failure, using apparatus and fixtures shown in Figures A 6 and A 7.	None

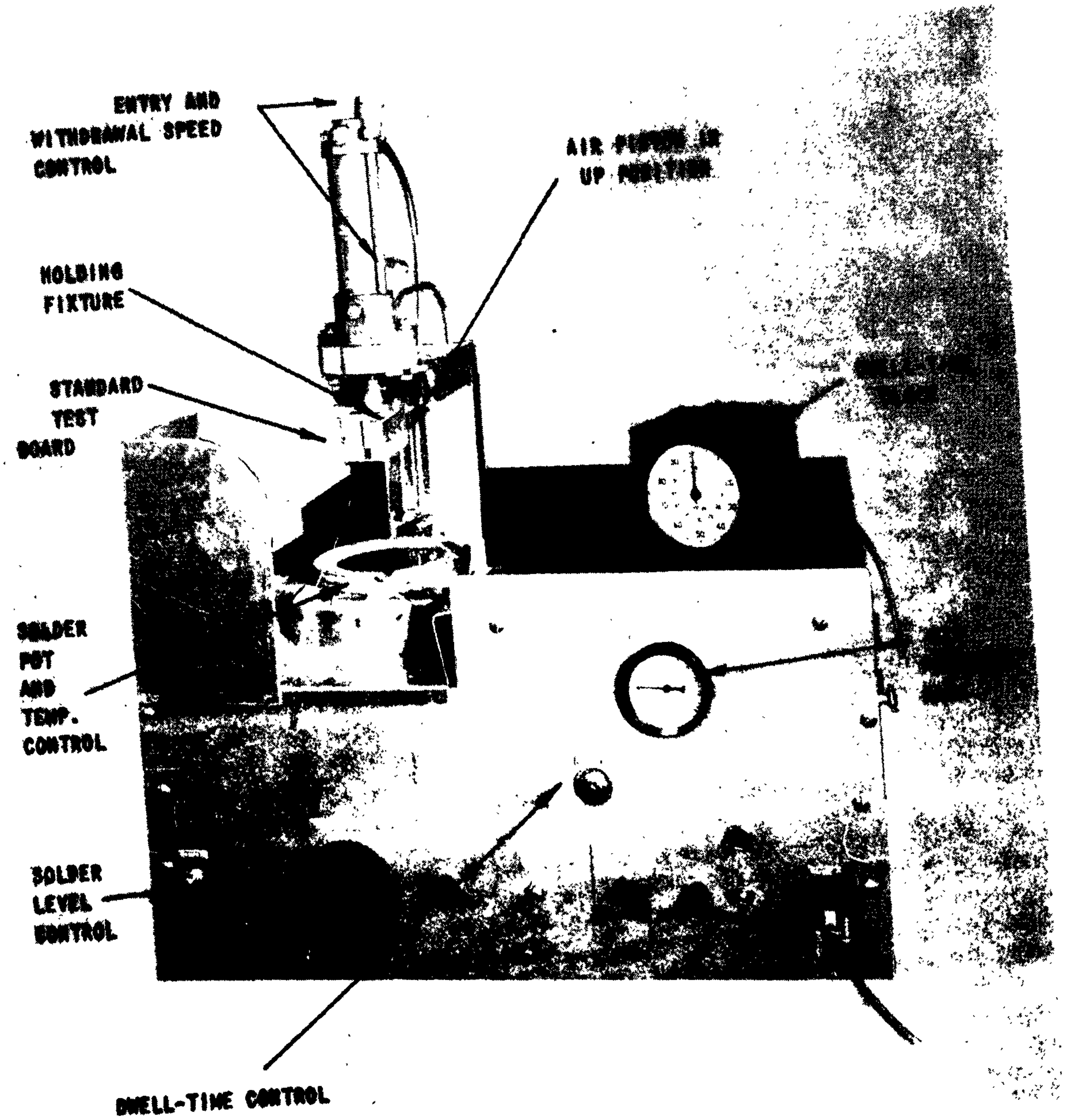


Figure A4. DIP SOLDERING EQUIPMENT (AIR PISTON IN UP POSITION)

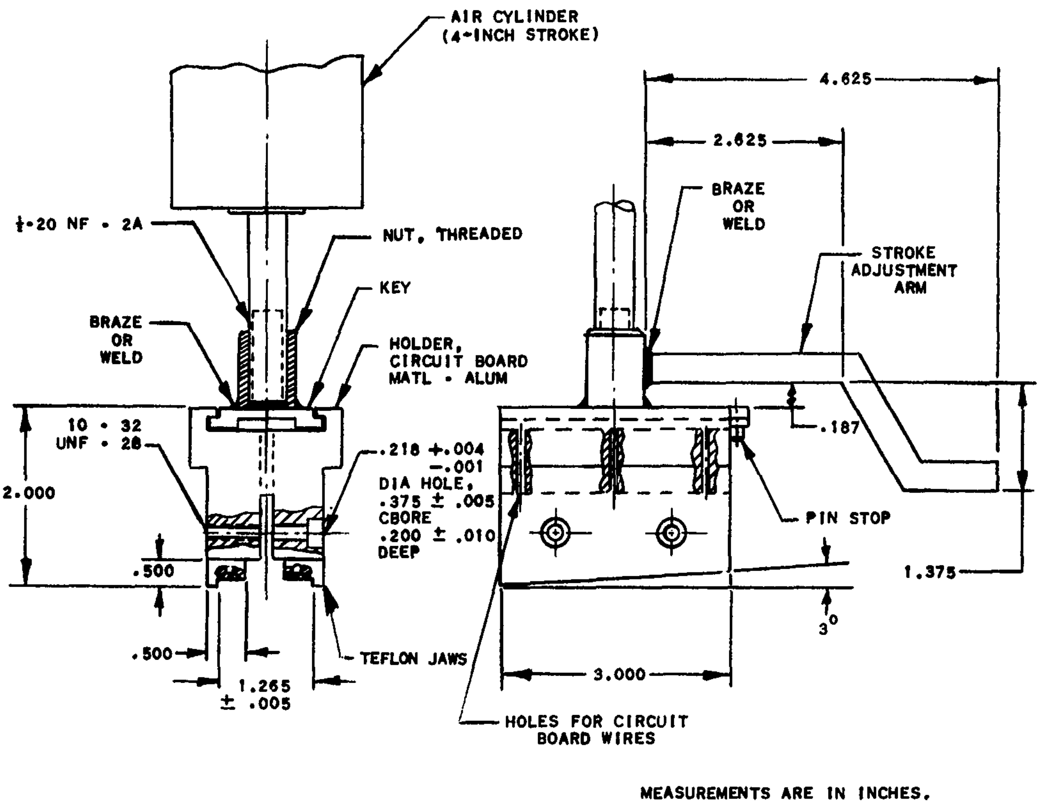


Figure A5. CIRCUIT BOARD HOLDER FOR DIP SOLDERING

Figure A6. INSTRON WIRE TESTING TENSILE MACHINE

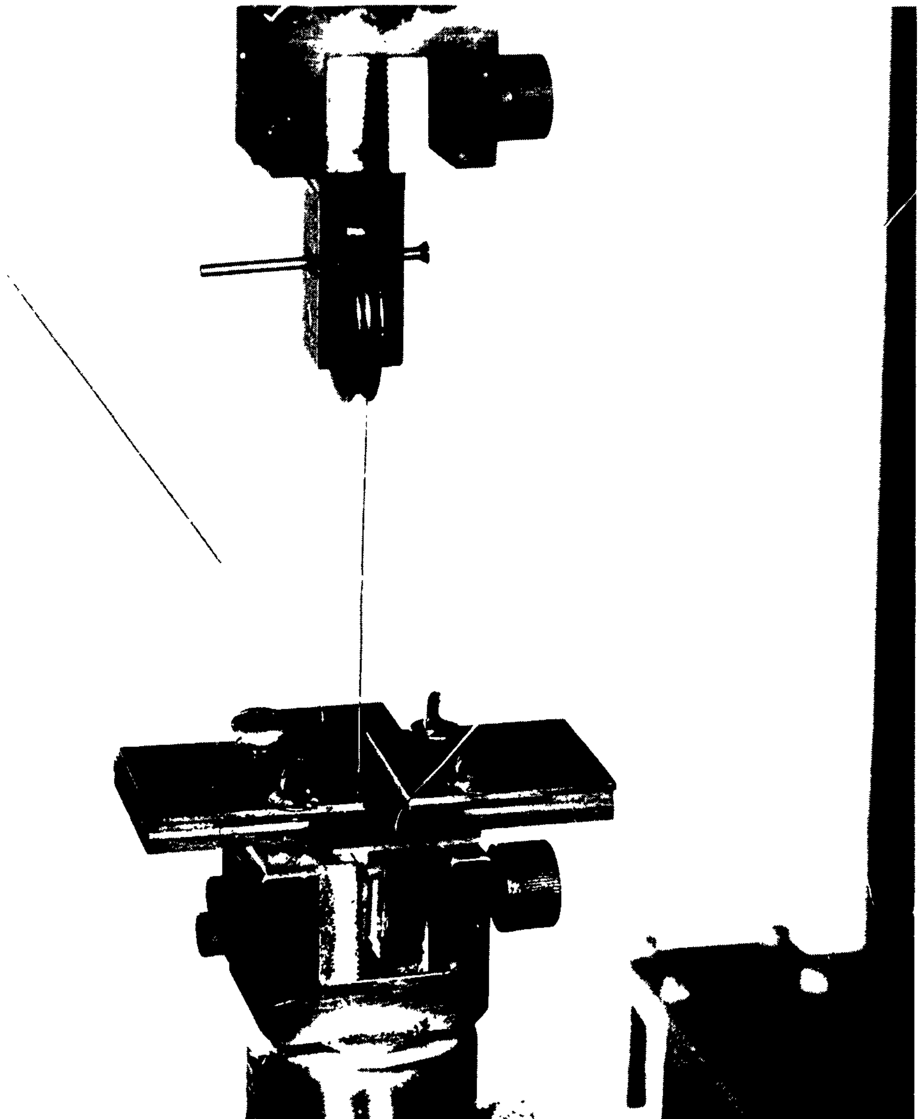


Figure A7. INSTRON WIRE TESTING TENSILE MACHINE, CLOSE UP OF CLAMPING JAWS

APPENDIX A (Cont'd.)

Parameter	Specification	Identification Code*
	b. Push from insulation side and record force in pounds required to cause joint failure, using apparatus and fixturing indicated in Figure A 8.	None
10. Environmental Tests		
A. Thermal Shock		
a. Fixturing	See Figure A 9	--
b. Method	See Figure A 10	--
B. Vibration		
a. Fixturing	See Figure A 11	--
b. Method	See Flow Chart, Figure A 12	--

*NOTE:

Variable factors which are likely to be changed within a given test group are assigned code designations for convenience in tabulating data. For instance, Code II-OX-2 indicated that the soldered joints were made under the following conditions:

II - Solder temperature, 600°F.

OX - The simulated component terminations were "solvent cleaned" and the terminal board terminations were "oxidized".

2 - Dwell time in the molten solder was one second.

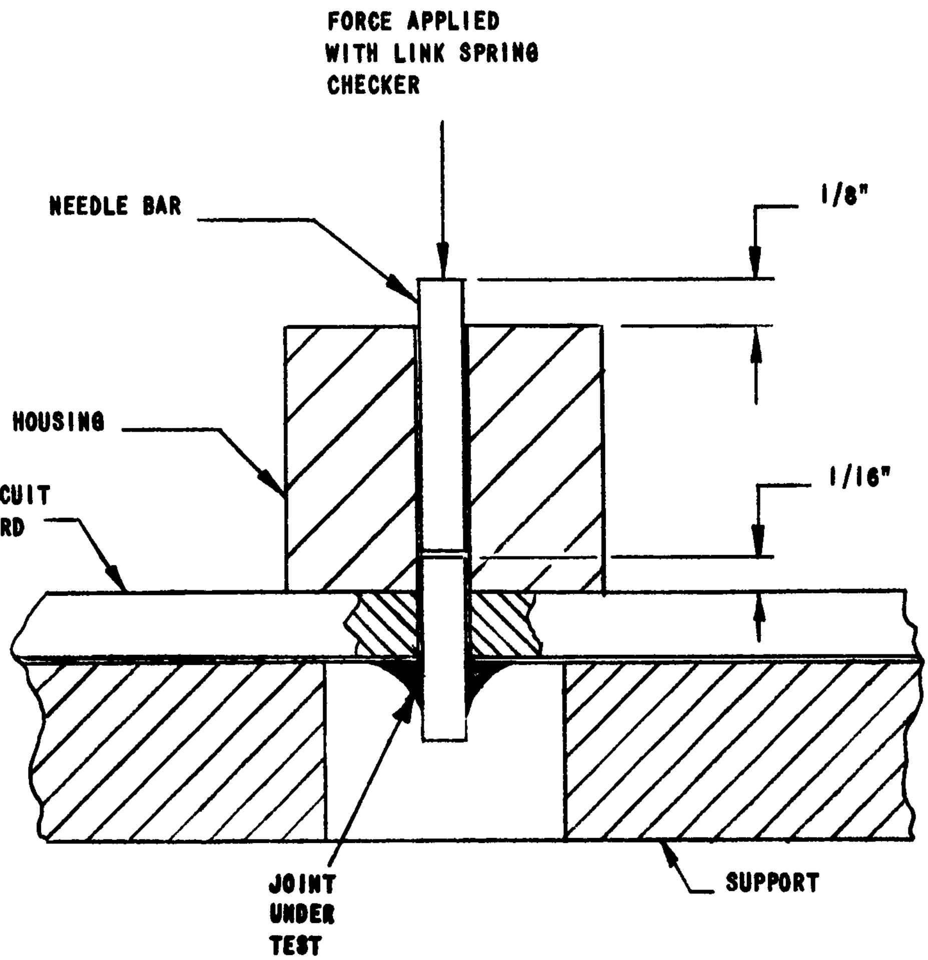


Figure A8. PUSH-OFF FIXTURE

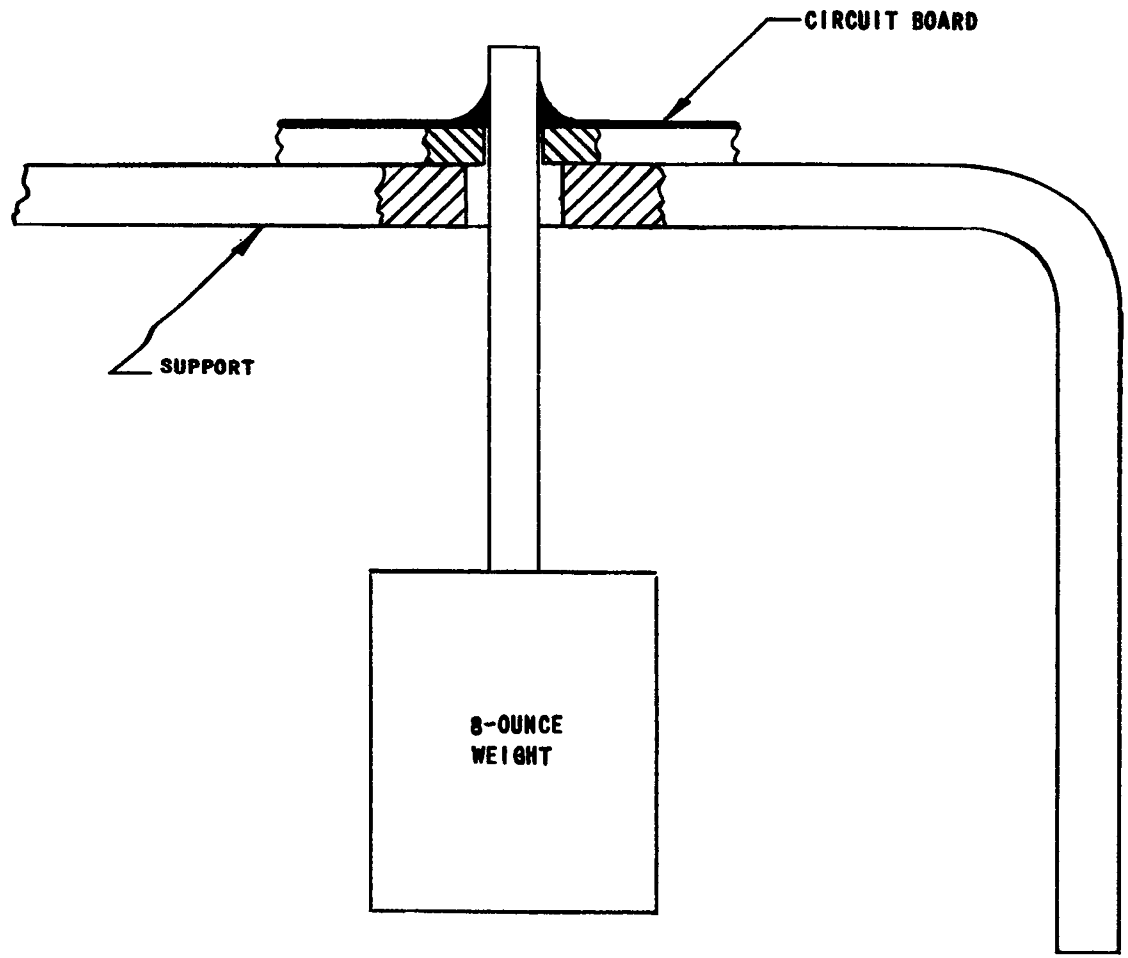


Figure A9. THERMAL SHOCK TEST FIXTURE

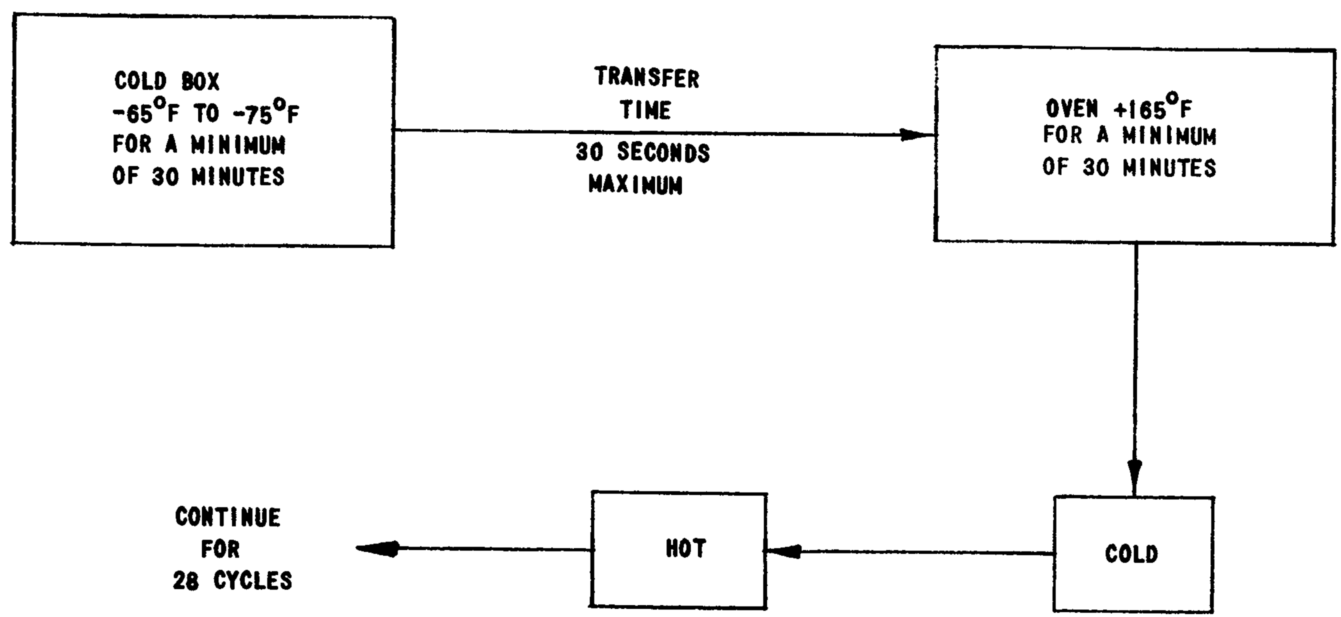


Figure A 10. THERMAL SHOCK FLOW DIAGRAM

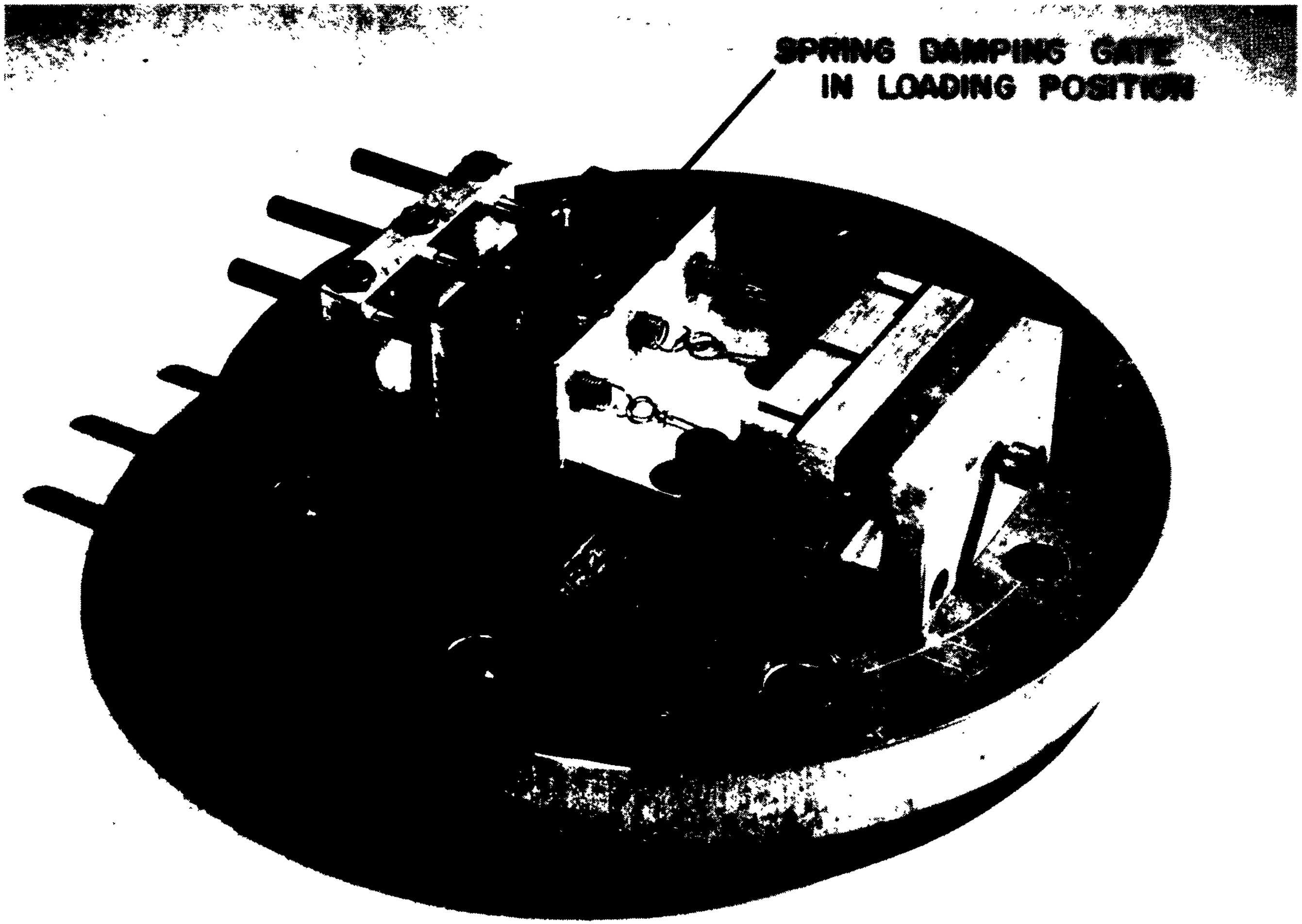
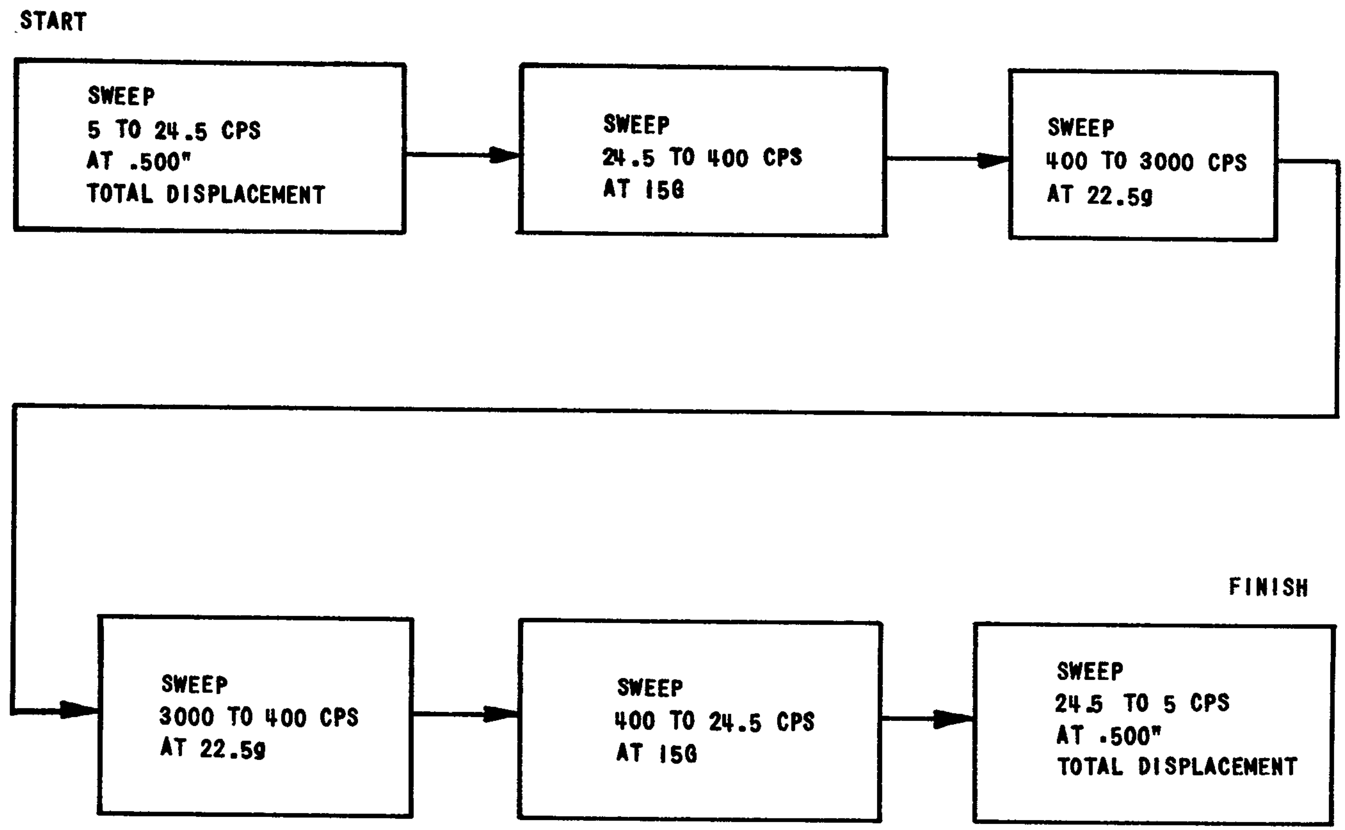


Figure A 11. VIBRATION FIXTURE, GATE OPEN



Total Time Start to Finish 90 Minutes

Figure A 12. FLOW DIAGRAM OF VIBRATION TEST CYCLE

APPENDIX B

Results of Tensile (Pull) Tests
Standard Test Assemblies

The reader is referred to Appendix A for a detailed description of the Tensile (Pull) Test, the test assemblies used to accumulate the data appearing on the following pages, and the code designations used to indicate solder joint quality. The inspection procedure is the same as that explained in Section II of the report, Part B, commencing on page 14.

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
1	XXXP	Gold	Hole	II-A-3	OK	16.5 WB**
2	XXXP	Gold	Hole	II-A-3	OK	16.4 WB
3	XXXP	Gold	Hole	II-A-3	OK	16.2
4	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
5	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
6	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
7	XXXP	Gold	Hole	II-A-3	OK	16.4 WB
8	XXXP	Gold	Hole	II-A-3	OK	13.6
9	XXXP	Gold	Hole	II-A-3	OK	14.8
10	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
11	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
12	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
13	XXXP	Gold	Hole	II-A-3	OK	16.4 WB
14	XXXP	Gold	Hole	II-A-3	OK	16.4 WB
15	XXXP	Gold	Hole	II-A-3	OK	16.3 WB
16	G-10	Gold	Hole	II-A-3	OK	16.3 WB
17	G-10	Gold	Hole	II-A-3	OK	16.4 WB
18	G-10	Gold	Hole	II-A-3	OK	16.3 WB
19	G-10	Gold	Hole	II-A-3	OK	16.4 WB
20	G-10	Gold	Hole	II-A-3	OK	16.3 WB
21	G-10	Gold	Hole	II-A-3	OK	16.3 WB
22	G-10	Gold	Hole	II-A-3	OK	16.3 WB
23	G-10	Gold	Hole	II-A-3	R	15.6
24	G-10	Gold	Hole	II-A-3	OK	16.3 WB
25	G-10	Gold	Hole	II-A-3	OK	16.3 WB

* OK = Accepted
R = Rejected
** WB = Wire Breaks

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
26	G-10	Gold	Hole	I-C-1	OK	15.3
27	G-10	Gold	Hole	I-C-1	OK	13.6
28	G-10	Gold	Hole	I-C-1	R	14.0
29	G-10	Gold	Hole	I-C-1	OK	13.9
30	G-10	Gold	Hole	I-C-1	R	15.0
31	G-10	Gold	Hole	I-C-1	OK	16.2 WB
32	G-10	Gold	Hole	I-C-1	OK	16.8 WB
33	XXXP	Gold	Hole	I-C-1	R	15.0
34	XXXP	Gold	Hole	I-C-1	OK	12.5
35	XXXP	Gold	Hole	I-C-1	OK	16.1
36	XXXP	Gold	Hole	I-C-1	R	16.6 WB
37	XXXP	Gold	Hole	I-C-1	R	15.9
38	XXXP	Gold	Hole	I-C-1	OK	15.3
39	XXXP	Gold	Hole	I-C-1	OK	16.4
40	XXXP	Gold	Hole	I-C-1	OK	15.9
41	XXXP	Gold	Hole	I-C-1	OK	12.8
42	XXXP	Gold	Hole	I-C-1	OK	16.2
43	XXXP	Gold	Hole	I-C-1	R	12.7
44	XXXP	Gold	Hole	I-C-1	OK	8.9
45	XXXP	Gold	Hole	I-C-1	R	13.9
46	XXXP	Gold	Hole	I-C-1	R	14.0
47	XXXP	Gold	Hole	I-C-1	OK	16.1
48	XXXP	Gold	Hole	I-C-1	OK	16.7 WB
49	XXXP	Gold	Hole	I-C-1	R	16.8
50	XXXP	Gold	Hole	I-C-1	R	10.5

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
51	XXXP	Gold	Hole	I-C-1	R	12.8
52	XXXP	Gold	Hole	I-C-0	R	15.4
53	XXXP	Gold	Hole	I-C-0	R	7.1
54	XXXP	Gold	Hole	I-C-0	OK	14.0
55	XXXP	Gold	Hole	I-C-0	OK	16.4
56	XXXP	Gold	Hole	I-C-0	OK	15.5
57	XXXP	Gold	Hole	I-C-0	R	9.0
58	XXXP	Gold	Hole	I-C-0	R	10.9
59	XXXP	Gold	Hole	I-C-0	R	16.2
60	XXXP	Gold	Hole	I-C-0	R	13.2
61	XXXP	Gold	Hole	I-C-0	R	13.8
62	XXXP	Gold	Hole	I-C-0	R	10.8
63	XXXP	Gold	Hole	I-C-0	OK	16.0
64	XXXP	Gold	Hole	I-C-0	R	15.6
65	XXXP	Gold	Hole	I-C-0	OK	13.8
66	XXXP	Gold	Hole	I-C-0	R	14.0
67	XXXP	Gold	Hole	I-C-0	OK	16.0
68	XXXP	Gold	Hole	I-C-0	OK	14.3
69	XXXP	Gold	Hole	I-C-0	R	14.4
70	XXXP	Gold	Hole	I-C-0	R	12.0
71	XXXP	Gold	Hole	I-C-0	R	12.8
72	XXXP	Gold	Hole	I-C-0	OK	12.7
73	XXXP	Gold	Hole	I-C-0	OK	12.2
74	XXXP	Gold	Hole	I-C-0	R	9.7
75	XXXP	Gold	Hole	I-C-0	R	9.1

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
76	XXXP	Gold	Hole	I-C-0	R	15.4
77	XXXP	Gold	Hole	I-C-0	R	11.4
78	XXXP	Gold	Hole	I-C-0	R	15.4
79	XXXP	Gold	Hole	I-C-0	OK	16.3
80	XXXP	Gold	Hole	I-C-0	OK	14.4
81	XXXP	Gold	Hole	I-C-0	R	0
82	XXXP	Gold	Hole	I-C-0	R	0
83	XXXP	Gold	Hole	I-C-0	R	13.4
84	XXXP	Gold	Hole	I-C-0	R	6.7
85	XXXP	Gole	Hole	I-C-0	R	13.8
86	XXXP	Gold	Hole	I-C-0	R	15.6
87	XXXP	Gold	Hole	I-C-0	OK	16.4 WB
88	XXXP	Gold	Hole	I-C-0	R	10.9
89	XXXP	Gold	Hole	I-C-0	R	9.1
90	XXXP	Gold	Hole	I-C-0	OK	13.2
91	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
92	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
93	XXXP	Solder	Hole	II-A-3	OK	16.4 WB
94	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
95	XXXP	Solder	Hole	II-A-3	OK	14.3
96	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
97	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
98	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
99	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
100	XXXP	Solder	Hole	II-A-3	OK	16.5 WB

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
101	XXXP	Solder	Hole	II-A-3	OK	15.5
102	XXXP	Solder	Hole	II-A-3	OK	16.4 WB
103	XXXP	Solder	Hole	II-A-3	OK	16.5 WB
104	G-10	Solder	Hole	II-A-3	R	16.5 WB
105	G-10	Solder	Hole	II-A-3	OK	16.5 WB
106	G-10	Solder	Hole	II-A-3	OK	16.4
107	G-10	Solder	Hole	II-A-3	OK	15.8
108	G-10	Solder	Hole	II-A-3	OK	16.6 WB
109	G-10	Solder	Hole	II-A-3	OK	16.5 WB
110	G-10	Solder	Hole	II-A-3	OK	16.5
111	G-10	Solder	Hole	II-A-3	OK	16.4 WB
112	G-10	Solder	Hole	II-A-3	OK	16.4 WB
113	G-10	Solder	Hole	II-A-3	R	16.4 WB
114	G-10	Solder	Hole	II-A-3	R	9.9
115	G-10	Solder	Hole	I-C-2	OK	15.2
116	G-10	Solder	Hole	I-C-2	OK	16.6 WB
117	G-10	Solder	Hole	I-C-2	OK	16.3
118	G-10	Solder	Hole	I-C-2	OK	16.5
119	G-10	Solder	Hole	I-C-2	OK	16.5
120	G-10	Solder	Hole	I-C-2	R	14.9
121	G-10	Solder	Hole	I-C-2	OK	16.4
122	G-10	Solder	Hole	I-C-2	OK	16.6 WB
123	G-10	Solder	Hole	I-C-2	R	16.7 WB
124	G-10	Solder	Hole	I-C-2	OK	16.6
125	G-10	Solder	Hole	I-C-2	OK	16.6

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
126	G-10	Solder	Hole	I-C-2	R	15.3
127	G-10	Solder	Hole	I-C-2	R	14.5
128	G-10	Solder	Hole	I-C-2	R	16.2
129	G-10	Solder	Hole	I-C-2	OK	16.6 WB
130	G-10	Solder	Hole	I-C-2	R	16.4 WB
131	G-10	Solder	Hole	I-C-2	R	16.4
132	G-10	Solder	Hole	I-C-2	R	16.2
133	G-10	Solder	Hole	I-C-2	OK	14.4
134	G-10	Solder	Hole	I-C-2	R	16.6
135	XXXP	Solder	Hole	I-C-1	R	9.0
136	XXXP	Solder	Hole	I-C-1	R	15.3
137	XXXP	Solder	Hole	I-C-1	OK	12.8
138	XXXP	Solder	Hole	I-C-1	OK	16.4
139	XXXP	Solder	Hole	I-C-1	OK	11.7
140	XXXP	Solder	Hole	I-C-1	OK	16.8
141	XXXP	Solder	Hole	I-C-1	OK	14.7
142	XXXP	Solder	Hole	I-C-1	R	14.2
143	XXXP	Solder	Hole	I-C-1	R	8.9
144	XXXP	Solder	Hole	I-C-1	R	10.4
145	XXXP	Solder	Hole	I-C-1	R	10.9
146	XXXP	Solder	Hole	I-C-1	OK	13.4
147	XXXP	Solder	Hole	I-C-1	R	16.4
148	XXXP	Solder	Hole	I-C-1	R	16.0
149	XXXP	Solder	Hole	I-C-1	R	15.2
150	XXXP	Solder	Hole	I-C-1	R	8.0

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
151	XXXP	Solder	Hole	I-C-1	OK	16.7 WB
152	XXXP	Solder	Hole	I-C-1	R	16.7 WB
153	XXXP	Solder	Hole	I-C-1	OK	16.7 WB
154	XXXP	Solder	Hole	I-C-1	R	15.1
155	XXXP	Solder	Hole	I-C-1	R	10.1
1	XXXP	Copper	Eyelet	I-C-0	R	8.6
2	XXXP	Copper	Eyelet	I-C-0	R	16.2
3	XXXP	Copper	Eyelet	I-C-0	OK	15.1
4	XXXP	Copper	Eyelet	I-C-0	OK	15.4
5	XXXP	Copper	Eyelet	I-C-0	OK	14.8
6	XXXP	Copper	Eyelet	I-C-0	R	0
7	XXXP	Copper	Eyelet	I-C-0	R	0
8	XXXP	Copper	Eyelet	I-C-0	R	0
9	XXXP	Copper	Eyelet	I-C-0	OK	14
10	XXXP	Copper	Eyelet	I-C-0	OK	15.6
11	XXXP	Copper	Eyelet	I-C-0	R	0
12	XXXP	Copper	Eyelet	I-C-0	R	0
13	XXXP	Copper	Eyelet	I-C-0	OK	12.2
14	XXXP	Copper	Eyelet	I-C-0	OK	16
15	XXXP	Copper	Eyelet	I-C-0	R	13
16	XXXP	Copper	Eyelet	I-C-0	R	15
17	XXXP	Copper	Eyelet	I-C-0	OK	16.4
18	XXXP	Copper	Eyelet	I-C-0	OK	12.8
19	XXXP	Copper	Eyelet	I-C-0	R	0
20	XXXP	Copper	Eyelet	I-C-0	OK	15.6

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)
1	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
2	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
3	XXXP	Copper	Wrap-Around	II-A-3	OK	16.6 WB
4	XXXP	Copper	Wrap-Around	II-A-3	R	16.8 WB
5	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
6	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
7	XXXP	Copper	Wrap-Around	II-A-3	OK	16.6 WB
8	XXXP	Copper	Wrap-Around	II-A-3	OK	16.7 WB
9	XXXP	Copper	Wrap-Around	II-A-3	OK	16.5 WB
10	XXXP	Copper	Wrap-Around	II-A-3	OK	16.6 WB
11	XXXP	Copper	Wrap-Around	II-A-3	R	16.8 WB
12	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
13	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
14	XXXP	Copper	Wrap-Around	II-A-3	OK	16.5 WB
15	XXXP	Copper	Wrap-Around	II-A-3	OK	16.7 WB
16	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
17	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
18	XXXP	Copper	Wrap-Around	II-A-3	OK	16.7 WB
19	XXXP	Copper	Wrap-Around	II-A-3	OK	16.6 WB
20	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
21	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
22	XXXP	Copper	Wrap-Around	II-A-3	OK	16.8 WB
23	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8 WB
24	XXXP	Copper	Wrap-Around	I-C-1	R	16.8 WB
25	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8 WB

APPENDIX B (Cont'd)

Joint No.	Board Insulation	Board Terminal Finish	Board Terminal Style	Joint Quality	Accepted or Rejected*	Pull to Failure (Pounds)	
26	XXXP	Copper	Wrap-Around	I-C-1	R	16.8	WB
27	XXXP	Copper	Wrap-Around	I-C-1	OK	16.5	WB
28	XXXP	Copper	Wrap-Around	I-C-1	R	16.5	WB
29	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8	WB
30	XXXP	Copper	Wrap-Around	I-C-1	R	16.6	WB
31	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8	WB
32	XXXP	Copper	Wrap-Around	I-C-1	OK	16.6	WB
33	XXXP	Copper	Wrap-Around	I-C-1	OK	16.6	WB
34	XXXP	Copper	Wrap-Around	I-C-1	R	15.8	
35	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8	WB
36	XXXP	Copper	Wrap-Around	I-C-1	OK	16.8	WB
37	XXXP	Copper	Wrap-Around	I-C-1	R	16.8	WB

APPENDIX C

Results of Tensile (Pull) Tests Random Commercial Assemblies

A detailed description of the Tensile (Pull) Test will be found in Appendix A. The inspection procedure is the same as that described in Section II of the report, Part B, commencing on page 17.

APPENDIX C (Cont'd.)

Camera Assembly (Figure 8): Random Joints from Material Rejected During Manufactur

Joint No.	Accepted or Rejected	Pull to Failure (Pounds)	
1	OK*	8.3	
2	R*	13.4	
3	OK	10.2	
4	OK	13.2	
5	OK	14.0	
6	R	14.8	WB**
7	R	11.2	
8	OK	16.0	WB
9	R	14.6	
10	R	4.1	
11	OK	10.7	
12	OK	12.9	
13	OK	8.0	
14	OK	11.8	
15	R	0	
16	R	0	
17	R	1	
18	R	0	
19	OK	8.0	
20	R	11.8	
21	OK	13.4	

* OK = Accepted
R = Rejected
**WB = Wire Breaks

APPENDIX C (Cont'd.)

Camera Assembly (Figure 8): Random Joints from Material Rejected During Manufacture

Joint No.	Accepted or Rejected	Pull to Failure (Pounds)
22	OK	12.0
23	R	7.8
24	OK	12.7
25	OK	16.3 WB
26	OK	11.5
27	R	7.5
28	OK	16.0 WB
29	R	14.3
30	R	12.2
31	OK	14.4
32	OK	15.2 WB
33	R	15.1 WB
34	R	14.5
35	R	13.0
36	R	12.9
37	R	8.7
38	R	8.9
39	R	5.6
40	R	8.2
41	R	13.8
42	R	15.3
43	R	10.6
44	OK	14.3
45	R	7.5

APPENDIX C (Cont'd.)

Camera Assembly (Figure 8): Random Joints from Material Rejected During Manufacture

Joint No.	Accepted or Rejected	Pull to Failure (Pounds)
46	OK	14.8 WB
47	R	0
48	R	0
49	OK	13.0
50	R	10.0
51	R	0
52	OK	14.8
53	R	12.6
54	R	0
55	OK	15.2
56	R	11.3
57	R	11.0
58	R	6.5

APPENDIX C (Cont'd.)

Telephone Switch Gear Assembly, 3" x 3" (Figure 9)

Assembly No.	Total Number of Joints	Number of Joints Rejected	Number of Circuit Board Defects
1	92	0	0
2	88	3	0
3	71	0	0
4	87	1	0
5	77	8	0
6	74	3	0
7	97	0	0
8	75	0	0
9	50	0	1
10	94	6	0
	805	21 (2.6%)	

APPENDIX C (Cont'd)

Telephone Switch Gear Assembly,8" x 12" (Figure 10)

Assembly Number	Number of Wire Joints Rejected (250/Assembly)	Number of Lug Joints Rejected (152/Assembly)	Number of Circuit Board Defects
1	2	30	0
2	2	68	0
3	4	32	0
4	5	33	0
5	4	10	1
6	3	47	0
7	5	42	0
8	9	40	1
9	8	51	0
10	3	10	0
11	1	36	0
12	6	92	0
13	5	100	0
14	12	92	0
15	2	92	0
16	3	90	2
17	3	112	0
18	12	92	0
19	2	72	0
20	2	120	0
21	5	90	0
22	6	88	0
23	7	96	0
24	6	92	0
25	12	98	0
26	12	90	0
27	9	142	0

APPENDIX D

Vibration Testing Data

The standard test assemblies used to obtain the data shown on the following pages were of XXXP Phenolic circuit board insulation with plain copper, drilled-hole circuit board terminals. The joint quality varied as indicated by the codes, definitions of which may be found in Appendix A.

A detailed description of the Vibration Tests, as well as the Tensile (Pull) Tests to which the assemblies were also subjected, is included in Appendix A. The inspection procedure is equivalent to or the same as that described in Section II of this report, Part B, commencing on page 17.

APPENDIX D

1. Data as Summarized in Figure 12

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)	
1	II-A-3	OK*	+75	1	16.2	
2	II-A-3	OK	+75	1	15.6	
3	II-A-3	OK	+75	1	16.8	
4	II-A-3	OK	+75	1	16.9	WB**
5	II-A-3	OK	+75	1	16.9	WB
6	II-A-3	OK	+75	1	17.0	WB
7	II-A-3	OK	+75	1	16.9	
8	II-A-3	OK	+75	1	17.0	
9	II-A-3	OK	+75	1	16.8	WB
10	II-A-3	OK	+75	1	16.8	WB
11	II-A-3	OK	+75	1	16.8	WB
12	II-A-3	OK	+75	1	15.6	
13	II-A-3	OK	+75	1	15.5	
14	II-A-3	OK	+75	1	17.0	WB
15	II-A-3	OK	+75	1	13.3	
16	II-A-3	OK	+75	1	17.0	WB
17	II-A-3	OK	+75	1	16.1	
18	II-A-3	OK	+75	1	16.0	
19	II-A-3	OK	+75	1	16.9	WB
20	II-A-3	OK	+75	1	16.0	

* OK = Accepted
R = Rejected
** WB = Wire Breaks

APPENDIX D (Cont'd)

I. Data as Summarized in Figure 12

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)
21	II-A-3	OK	+75	1	16.9 WB
22	II-A-3	OK	+75	1	17.0 WB
23	II-A-3	OK	+75	1	15.2
24	II-A-3	OK	+75	1	17.0 WB
25	II-A-3	OK	+75	1	16.9
26	II-A-3	OK	+75	1	16.7
27	II-A-3	OK	+75	1	15.1
28	II-A-3	OK	+75	1	16.3
29	II-A-3	OK	+75	1	16.0
30	II-A-3	OK	+75	1	16.9 WB
1	II-A-3	OK	— ***	—	15.4
2	II-A-3	OK	—	—	14.8
3	II-A-3	OK	—	—	16.6 WB
4	II-A-3	OK	—	—	16.5 WB
5	II-A-3	OK	—	—	15.7
6	II-A-3	OK	—	—	16.6 WB
7	II-A-3	OK	—	—	16.6 WB
8	II-A-3	OK	—	—	16.5 WB
9	II-A-3	OK	—	—	16.1
10	II-A-3	OK	—	—	16.6

*** Absence of data indicates that joints were used as controls and were not vibrated.

APPENDIX D (Cont'd)

I. Data as Summarized in Figure 12

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)
11	II-A-3	OK	—	—	14.5
12	II-A-3	OK	—	—	16.5
13	II-A-3	OK	—	—	16.4
14	II-A-3	OK	—	—	16.2
15	II-A-3	OK	—	—	16.0
16	II-A-3	OK	—	—	16.5 WB
17	II-A-3	OK	—	—	16.4
18	II-A-3	OK	—	—	16.5
19	II-A-3	OK	—	—	14.6
20	II-A-3	OK	—	—	16.5 WB
21	II-A-3	OK	—	—	15.6
22	II-A-3	OK	—	—	16.6 WB
23	II-A-3	OK	—	—	16.7 WB
24	II-A-3	OK	—	—	16.6 WB
25	II-A-3	OK	—	—	15.7
26	II-A-3	OK	—	—	16.6 WB
27	II-A-3	OK	—	—	15.8
28	II-A-3	OK	—	—	16.6
29	II-A-3	OK	—	—	15.8
30	II-A-3	OK	—	—	16.7 WB
31	II-A-3	OK	—	—	16.9
32	II-A-3	OK	—	—	16.8 WB

APPENDIX D (Cont'd)

I. Data as Summarized in Figure 12

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)
33	II-A-3	OK	—	—	16.3
34	II-A-3	OK	—	—	15.7
35	II-A-3	OK	—	—	15.9
36	II-A-3	OK	—	—	16.8 WB

APPENDIX D (Cont'd)

2. Data as Summarized in Figure 13

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)
1	I-C-1	R	—	—	0
2	I-C-1	R	—	—	13.2
3	I-C-1	R	—	—	15.3
4	I-C-1	R	—	—	11.3
5	I-C-1	R	—	—	11.5
6	I-C-1	R	—	—	14.7
7	I-C-1	R	—	—	14.6
8	I-C-1	R	—	—	13.6
9	I-C-1	R	—	—	13.5
10	I-C-1	R	—	—	4.5
11	I-C-1	R	—	—	14.2
12	I-C-1	R	—	—	12.4
13	I-C-1	R	—	—	11.5
14	I-C-1	R	—	—	14.5
15	I-C-1	R	—	—	11.2
16	I-C-1	R	—	—	0
17	I-C-1	R	—	—	12.8
18	I-C-1	R	—	—	4.9
19	I-C-1	R	—	—	5.7
20	I-C-1	R	75	1	8.6
21	I-C-1	R	75	1	16.1
22	I-C-1	R	75	1	14.7
23	I-C-1	R	75	1	9.7

APPENDIX D (Cont'd)

2. Data as Summarized in Figure 13

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)
24	I-C-1	R	75	1	15.5
25	I-C-1	R	75	1	12.0
26	I-C-1	R	75	1	16.1
27	I-C-1	R	75	1	3.9
28	I-C-1	R	75	1	14.3
29	I-C-1	R	75	1	0
30	I-C-1	R	75	1	5.6
31	I-C-1	R	75	1	15.7

APPENDIX D (Cont'd)

3. Data as Summarized in Figure 14

Joint No.	Joint Quality	Accepted or Rejected	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Pull to Failure (Pounds)	
1	II-A-3	OK	-65	1	16.0	
2	II-A-3	OK	-65	1	16.2	
3	II-A-3	OK	-65	1	14.4	
4	II-A-3	OK	-65	1	14.3	
5	II-A-3	OK	-65	1	16.8	
6	II-A-3	OK	-65	1	16.6	
7	II-A-3	OK	-65	1	16.8	WB
8	II-A-3	OK	-65	1	14.6	
9	II-A-3	OK	-65	1	13.8	
10	II-A-3	OK	-65	1	16.6	WB
11	II-A-3	R	-65	1	16.6	WB
12	II-A-3	OK	-65	1	16.4	
13	II-A-3	OK	+165	1	16.6	
14	II-A-3	OK	+165	1	15.5	
15	II-A-3	OK	+165	1	16.5	
16	II-A-3	OK	+165	1	15.6	
17	II-A-3	OK	+165	1	14.4	
18	II-A-3	OK	+165	1	16.6	
19	II-A-3	OK	+165	1	15.8	
20	II-A-3	OK	+165	1	16.2	WB
21	II-A-3	OK	+165	1	14.2	
22	II-A-3	OK	+165	1	15.8	
23	II-A-3	OK	+165	1	16.7	
24	II-A-3	OK	+165	1	16.8	WB

4. Data as Summarized in Figure 15

Joint No.	Joint Quality	Vibration Test Temperature (°F)	Number of Standard Vibration Cycles	Before Vibration	Accepted or Rejected: After One Vibration Cycle	After Two Vibration Cycles	After Three Vibration Cycles	Pull to Failure (Pounds)
1	II-A-3	75	2	OK	OK	OK	—	16.6
2	II-A-3	75	2	OK	OK	OK	—	15.0
3	II-A-3	75	2	OK	OK	OK	—	13.5
4	II-A-3	75	2	OK	OK	OK	—	15.1
5	II-A-3	75	2	OK	OK	OK	—	13.9
6	II-A-3	75	2	OK	OK	OK	—	13.6
7	II-A-3	75	3	OK	OK	OK	OK	13.8
8	II-A-3	75	3	R	R	R	R	13.6
9	II-A-3	75	3	OK	OK	OK	OK	13.5
10	I-C-0	-65	1	R	R	—	—	1.4
11	I-C-0	-65	1	R	R	—	—	0
12	I-C-0	-65	2	R	R	R	—	0
13	I-C-1	-65	1	OK	R	—	—	13.2
14	I-C-1	-65	3	OK	OK	OK	OK	14.4
15	I-C-1	-65	2	R	R	R	—	5.3
16	I-C-1	-65	3	R	R	R	R	9.0
17	I-C-2	-65	2	OK	R	R	—	15.2
18	I-C-2	-65	3	OK	R	OK	OK	14.9

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